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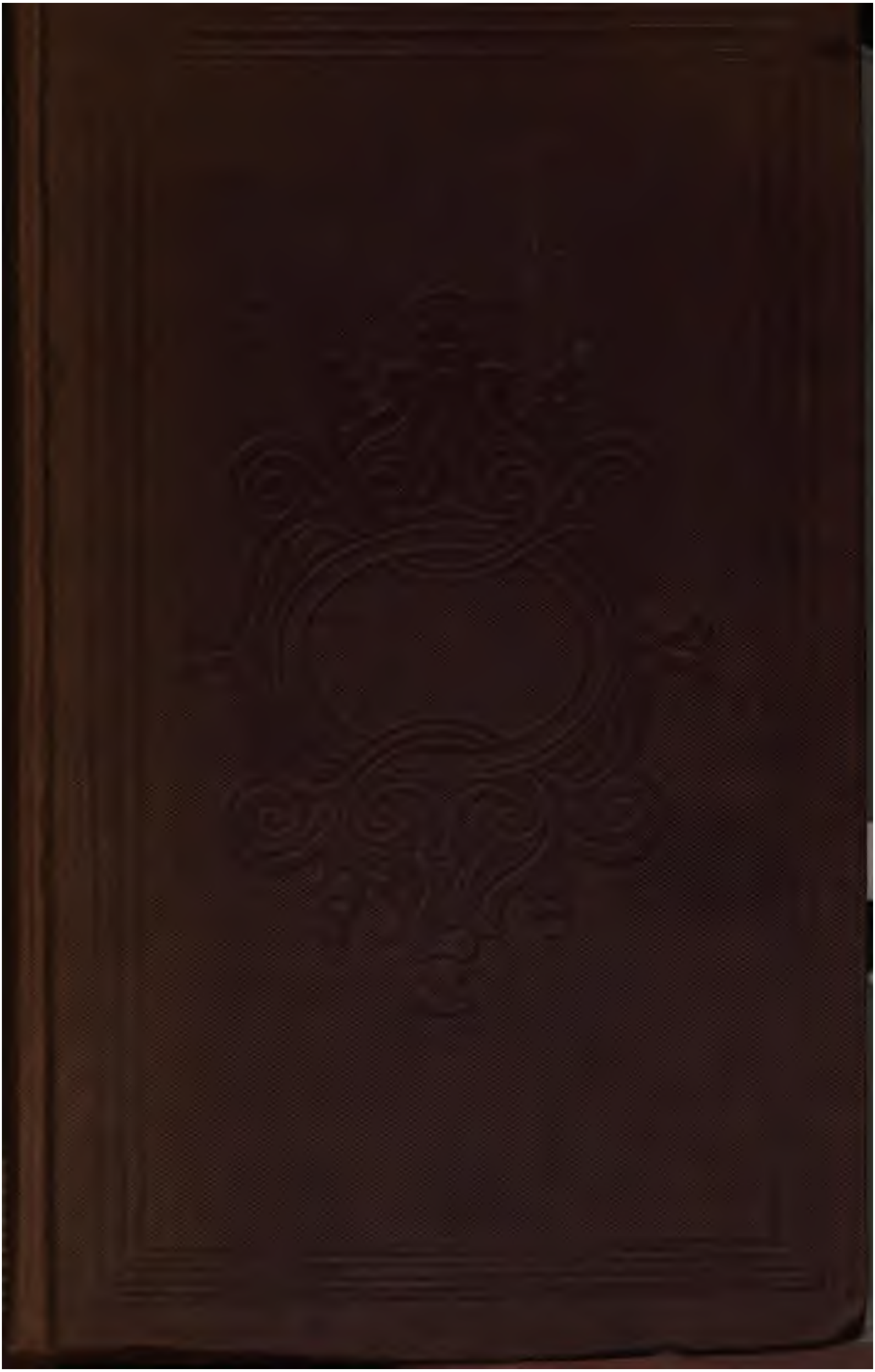

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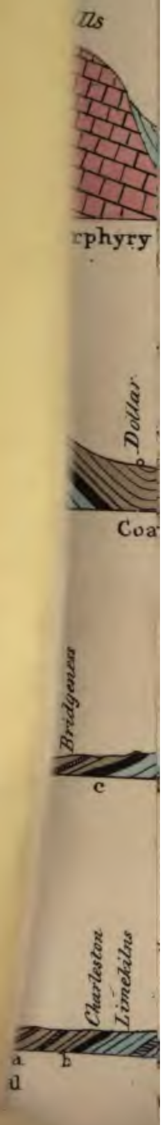
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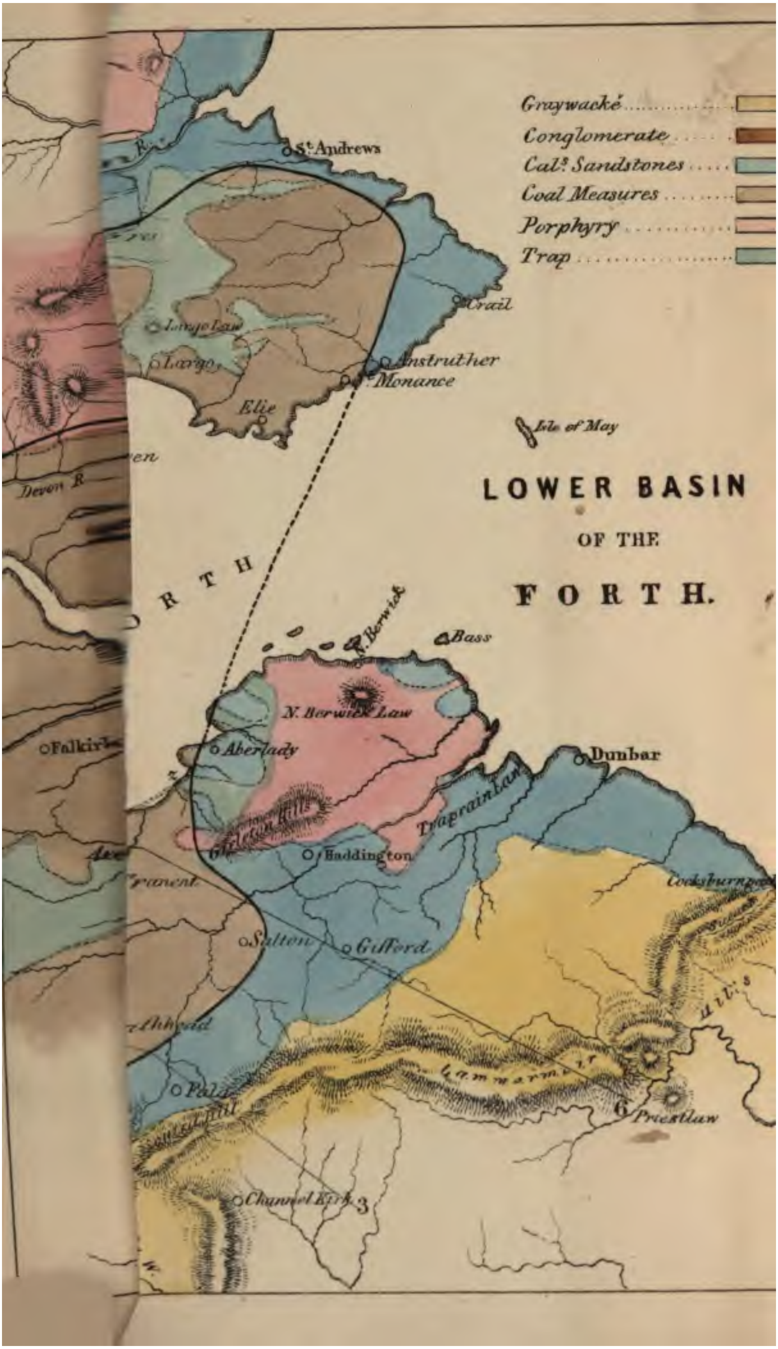
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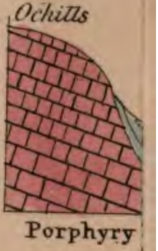
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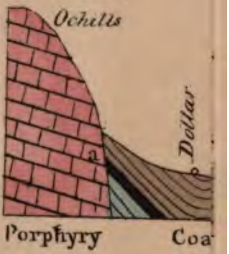
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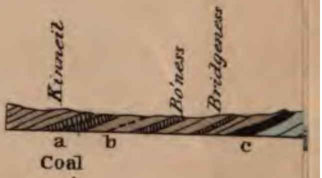
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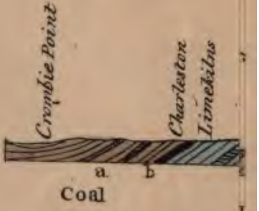
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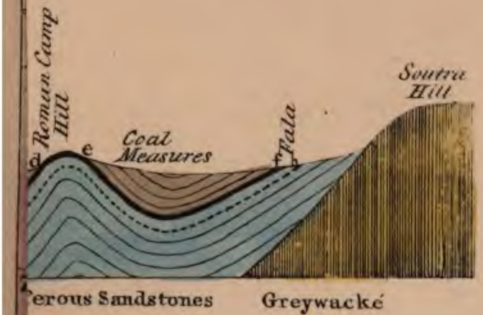
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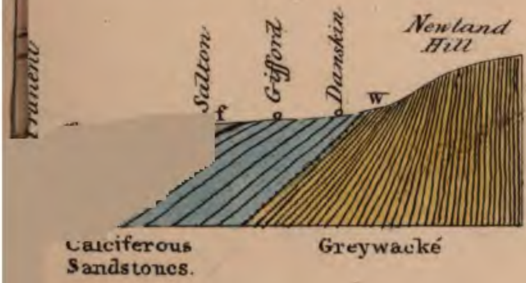
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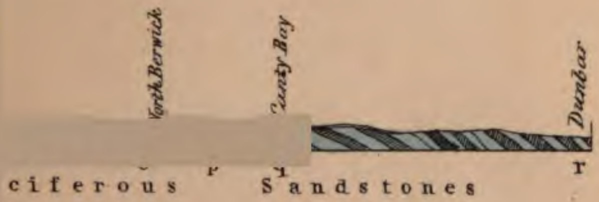
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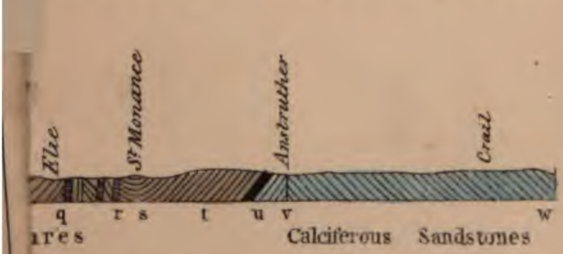
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A
SKETCH OF THE GEOLOGY
OF
FIFE AND THE LOTHIANS,

INCLUDING

DETAILED DESCRIPTIONS

OF

ARTHUR'S SEAT AND PENTLAND HILLS.

BY

CHARLES MACLAREN, Esq., F. R. S. E.

EDINBURGH:
ADAM AND CHARLES BLACK;
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PREFACE.

The original object of this work was to describe the structure of Arthur's Seat and the Pentland Hills ; but as it seemed desirable to shew the connections of these with the formations of the adjoining country, a geological sketch of the district between the Ochil and the Lammermuir Hills, constituting the lower basin of the Forth, was prepared and is inserted.

To the description of the rocks has been added a brief account of the older and newer alluvium, and a summary of the evidence from which a rise in the bed of the Firth of Forth has been inferred. Since this part of the work was written, an excellent memoir on the subject has been published in the Edinburgh Philosophical Journal by Mr Smith of Jordanhill, of which I would have been happy to avail myself of it had it appeared a little earlier. Mr David Milne, advocate, read, in the Royal Society, last winter, two able papers on the Mid-Lothian coal-field, and the superficial deposits of the basin of the Forth, from both of which, had they been printed, I would have derived much valuable information. Owing to indisposition I was not present when the former was submitted to the Society, and though I heard the latter read, I did not consider myself entitled to make use of Mr Milne's researches before he had given them to the public. My remarks on these deposits were written in the summer of 1837, and have only received some small additions and corrections from observations of my own subsequently made.

Mr R. J. H. Cunningham has published, in the Memoirs of the Wernerian Society, an elaborate paper on the Geology of the Lothians, for which he received a prize. Besides adding greatly to our knowledge of the extent and limits of the different formations, by his carefully prepared map, Mr Cunningham has thrown out many original and valuable remarks, and has given beautiful and accurate sections of some of the most interesting geological phenomena in the district. I did not see his memoir till the last sheets of this work were in the press, and I do not think it necessary to advert to the differences between his descriptions of the rocks and mine. They are to a great extent differences of method and arrangement.

In extenuation of the many errors and imperfections which will doubtless be found in this work, I might justly plead the difficulty of the subject, and the very limited amount of information previously accessible. These, however, are but a part of the disadvantages under which I laboured. My avocations did not permit me to devote more than a few days of each summer to the necessary surveys; and as the most ample written notes comprehend but a fraction of what the newly-stored memory retains, it happened, unavoidably, that much of the information collected in one season was forgotten before the next arrived, and researches, which might have been completed in three or four months, were extended over seven years, to the prejudice, no doubt, of their accuracy and consistency. The composition of the work has also been executed by short snatches, and amidst continual interruptions. If I were to say, that it has been as often dropped and resumed as it contains pages, I would not overstep the truth.

Though many of the descriptions given will have little interest except to professed geologists, my aim throughout has been to render the work intelligible to persons who have never studied the science, and various details and illustrations have been introduced for this purpose.

I am indebted to Mr Jardine, civil engineer, and Mr Bald, mining engineer, for several valuable communications; but my greatest obligations are to Professor Jameson, and his nephew

Mr William Jameson, assistant-surgeon in the service of the East India Company. All who have examined the porphyries of the Pentlands are aware of the perplexing variety of aspects they assume, of the difficulty of discriminating the species, and even, in some cases, of separating the igneous rocks from the sedimentary. The Professor, with his usual kindness to an old pupil, most obligingly resolved my doubts as often as I applied to him; and, when delicacy forbade me to encroach too far on his time, I was generally assisted by his nephew, who has rendered himself a most accomplished geologist and naturalist, at an early age, by enthusiastic study. I must not, however, make my friendly instructor responsible for errors which are mine. I was obliged to rely on my own judgment in many cases; and even when guided by the Professor's superior skill, the descriptive language employed being my own, no doubt sometimes involves inaccuracies and mistakes.

The theoretical view of the structure of Arthur's Seat is substantially the same with that which I published about five years ago, in a series of articles in the *Scotsman* newspaper. The descriptive part, which was then very faulty, will I hope now be found correct.

Some will blame me for indulging so much in speculation. I can only plead in my defence, that geological researches would be uninteresting to those who conduct them, and still more to those who read the results, if they were confined to a detail of facts, and separated from the study of causes. To this study, the science, it may be truly said, constantly invites, and though many of the processes which Nature employs still remain mysteries, enough is known respecting the origin of the igneous and sedimentary rocks, to afford elucidations and suggestions which the reader generally moulds into theories for himself, if the writer, who ought to be better informed, does not take the task out of his hands. In geological books, it is rather the abuse than the use of speculations which should be guarded against. Hypotheses founded on gratuitous assumptions, such as Burnet's central abyss of waters, or Whiston's shock of a comet, serve only to divert men's minds from the legitimate paths of investigation, but theories which take their departure from admitted facts or principles, such as the originally fused state of the igneous rocks, the gradual deposition of the sedimentary, the disturbing influence of upheaving forces, and the denuding action of water—such theories, followed out with moderation, and proposed as conjectural or probable explanations of phenomena, of which we have not a full and perfect knowledge, are not only admissible, but advantageous. They afford incentives to study, by bestowing an interest on details which would otherwise be intolerably dry, and become clues to minute and accurate observation, by indicating the points to which inquiry and research should be directed.

I have explained, at p. 69, the motives which led me to introduce the term "calciferous sandstones." It was not done from any love of innovation. On the contrary, I was most anxious to adhere to the nomenclature of the English geologists, but could not contrive any means of reconciling it with the order in which the formations present themselves in this part of the country. If the conglomerates of the Pentlands could have been transferred to another class, such as Mr Murchison's "Silurians," the words "Calciferous and Red Sandstones" would have better expressed the idea I wished to convey, namely, that these rocks blended the characters of the Mountain Limestone and old Red Sandstone of the English geologists; but I had no authority to make such a transference of the conglomerates. As the classification I have adopted does not satisfy myself, I cannot expect that it will satisfy others. I wish it, however, to be distinctly understood, that it is not proposed for general acceptance, but merely as a temporary expedient to elude difficulties which I was unable to solve, and I shall most cheerfully adopt any better arrangement which others may bring forward.

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ERRATA.

Page 137, 5th line from the bottom, *for* northern limestone, *read* northern direction
.... 139, 3d line from bottom, *for* tine of section, *read* line of section
.... 153, 10th line from top, *for* traps, *read* porphyries
.... 162, 13th line from bottom, *for* g, *read* f
.... 165 is erroneously printed 168

EXPLANATIONS RESPECTING THE MAPS AND SECTIONS.

MAP OF ARTHUR'S SEAT.

In the Map of Arthur's Seat, a key to the colours should have been inserted. The following will supply its place.

The Blue indicates Sandstone and Shale.

The Green, Trap, viz. Basalt, Greenstone, Amygdaloid, and Porphyritic Trap.

The Crimson, Trap-tuff.

MAP OF THE LOWER BASIN OF THE FORTH.

This map is borrowed from Dr MacCulloch's Geological Map of Scotland, with a few alterations, some of which are derived from my own inquiries, and for others I am indebted to Mr Robert Bald, Mr Jardine, and Mr Landale.

The heavy black line denotes the upper thick bed of limestone, which I have assumed as the lower limit of the "Coal Measures." Its position is known at many parts, but at others is laid down from conjecture. The small scale of the map, and the limited extent of my researches in the district generally, forbade any attempt at minute accuracy.

All the sandstone and shale below this limestone are referred to the class of "Calciferous Sandstones," till we come to the conglomerate seen in the Pentlands, or the breccia seen on the north side of the Ochils. I have no doubt that some portions of this breccia exist also on the south side of the Ochils, but I have not attempted to lay them down, as my examination of the hills was limited to one or two points.

The parts coloured green mark local tracts, where the trap rocks *abound*; but the reader must be on his guard against supposing that they occupy the whole surface,—sandstone and shale being invariably mixed with them, and often greatly exceeding the trap in quantity.

The smaller scale of the map compelled me in several places to unite trap areas which Dr MacCulloch has divided.

The portion of the Fife Coal Measures, extending from Culross to St Andrew's, might have been referred to the Calciferous Sandstones with perhaps equal propriety, the trap having everywhere forced up the inferior beds to the surface, as explained at page 105.

I have attempted to discriminate the Traps from the Porphyries, which are blended in Dr MacCulloch's map; but, except in the Pentlands, the boundaries I have assigned are in a great measure arbitrary.

The uneven line x, y, z, indicates a large greenstone vein, extending from Edinburgh to the vicinity of Aberlady. Reference is made to it at pages 27 and 86.

The basis of the plan of colouring adopted was this:—The Coal Measures were distinguished by the blackish-brown tint which is generally appropriated to this group of rocks in the English geological maps; and a blue tint was given to the formation below, because it corresponds in position, and partly in character, with the Mountain Limestone, which is generally so coloured in the maps alluded to. The other colours, yellow, brown, pink, and green, were selected on the principle of contrast.

MAP OF PENTLAND HILLS.

The topography of this map is founded on that of Mr Knox, to the great accuracy of which, so far as regards the hills, I can bear testimony. The geological part is entirely the result of my own observations. I have bestowed considerable pains in tracing the boundaries of the different formations, but it is scarcely necessary to say, that where so much of the surface is covered with turf or gravel, minute accuracy is impossible.

SECTIONS I. II. III. IV.

These sections are coloured, and the small cross-lined spaces denote beds or masses of trap. These beds are figured as of limited depth, because we know them to be so in many instances, but the reader must not suppose that this holds true in all cases, or that the depth shewn in the drawing, is meant to represent their actual depth in nature, which rarely comes within our knowledge.

The length and height of the sections being on very different scales, all the inclinations are represented as much higher than they are in nature.

The heavy black line in these sections also indicates the upper thick bed of limestone.

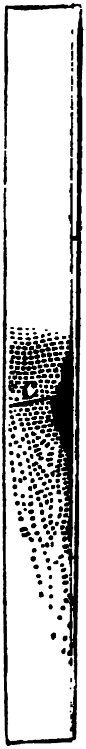
SECTIONS V. VI. VII. VIII. IX. X. XI.

These sections extend across the Pentland Hills, along the lines indicated by corresponding numbers on the map. The rocks being named underneath, and otherwise distinguished by engraved characters, it has not been thought necessary to employ colours.

In Section XI. there is an error resulting from an oversight, which is corrected in a Note at the end of the work.

It is convenient to express the magnitude of erratic blocks, or boulders, in some cases by their weight instead of their bulk. The rule I use for this purpose is, to reckon a cubic yard of rock equal to two tons in weight, which is nearly correct.

Young geologists will also find the following rule convenient. If the breadth of inclined strata is measured across their outcrop, at right angles to the direction, their true thickness will be equal to 1-12th of their apparent thickness for every 5° of inclination. Thus, suppose we find a mass of strata to measure 1200 feet across—if the dip is 5°, the thickness will be 1-12th, or 100 feet; if the dip is 10°, it will be 2-12ths, or 1-6th, or 200 feet; if the dip is 15°, it will be 1-4th, or 300 feet; if the dip is 20°, it will be 1-3d, or 400 feet, and so on. Or it may be put thus—" divide 60 by the dip, and you obtain the fraction which expresses the thickness." The rule is not quite correct when the dip exceeds 45°, but it is sufficiently so for geological purposes.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A SKETCH, &c.

GEOLOGY OF ARTHUR'S SEAT.

Arthur's Seat is an isolated hill, rising abruptly from a level country, to the height of 820 feet above the sea, with a bold craggy outline; and for grandeur and picturesque effect, is worth all the temples and monuments of London and Paris put together. It is so near Edinburgh, that it may be said to be in contact with the eastern parts of it. The lower portion of the hill is chiefly of sandstone; the upper is entirely of trap, that is, of rocks of volcanic or igneous origin, of which the familiar name in this country is *whinstone*. Salisbury Crags and Arthur's Seat form properly only one hill, and I shall describe them as such, though I may on some occasions speak of them separately. For the sake of reference, however, it is indispensable to give *names* to their more prominent parts, and where these do not already exist, I have taken the liberty to invent new ones. As this work may pass into the hands of persons in distant parts of Scotland and England, I must also go into details which readers in this district may consider superfluous.

The figure prefixed is a map or ground-plan of the hill; and includes a space about one mile in length from east to west, and three quarters of a mile in breadth from south to north. An inch of length corresponds nearly to 1000 feet. The heavy black lines denote the edges or outcrop of beds of greenstone or basalt.

EXPLANATION OF THE MAP.

c, St Leonard's Hill.
F F, Salisbury Crag.
G, The Hunting Bog, a swampy hollow separating the Crags from Arthur's Seat.
A, The *Apex* or summit of the hill.
B, The *North Limb* of the hill.
C D, The *South Limb*.
E, A small prominent rock called *Dunsapy*, which has a marsh on its west side.
H, Duddingston Loch.

1, 2, 3, 4, St Leonard's Crag, running in a winding direction from the Dumbie House near *c*, to the columnar rocks called Samson's Ribs, at 4. The rock at 1, towards St John's Hill, though detached from this, is a portion of the same bed. The height of St Leonard's Crag above the sea, is about 260 feet at 2; it is 300 feet at 3, (the *Echoing Rock,*) and 350 at the top of Samson's Ribs. *a*, Is the site of the steam-engine, and termination of the Dalkeith Railway.
5, 6, 7, Salisbury Crag, about 570 feet above the sea at its western and highest point 6, and about 330 feet at its southern termination, near 7. The short black line at 6, is the greenstone vein, which was the subject of much controversy between the Huttonians and Wernerians about twenty years ago.
8, 9, Two masses of greenstone, different from the greenstone of Salisbury Crag on which they rest.
10, An old sandstone quarry.
11, Large greenstone boulders marked ×, scattered over the surface. Some are found at G, and farther southward.
12, A small detached rock. It is a portion of the Crag 13, 14, 15.
13, The site of St Anthony's Well. *b*, The ruined chapel.
16, 17, *Bog Crag*, so named from being nearest to the Hunting Bog.
13, 14, 15, *Well Crag*, from the spring called St Anthony's Well, (13,) at its north end.
18, 19, 20, A bed of blue basalt resting on traptuff.
21, 22, A bed of reddish basalt, divided from the last by a bed of amygdaloid from two yards to ten in thickness.
23, 24, A third bed of basalt, of a greenish-blue colour, passing into red in its upper part.
25, 26, A bed of amygdaloidal trap porphyry.
27, 28, Another bed of amygdaloidal trap porphyry.
The five last-named beds constitute the *north limb* of the hill, the highest part of which is about 570 feet above the sea. The three westmost, marked by black lines, I call St Anthony's Crags, No. 1, 2, 3.
29, 30, The *Apex* or summit A, consisting of an oval-shaped mass of columnar basalt.
31, 32, *Girnal Crag*, the south end of which is washed by Duddingston Loch. The footpath passes through an opening in this rock, between 31 and 32, called Windygowl. I consider *Girnal Crag as a continuation of Bog Crag*, marked 16, 17, on the opposite side of the hill.
33, *Loch Crag*, (so I name it,) parallel to Girnal Crag, and about 200 feet eastward. *It seems a continuation of Well Crag*, marked 13, 14, 15, on the north side of the hill.
34, A slightly marked crag of amygdaloid, which seems to be a continuation of beds of the north limb B.

D, A large bed of porphyritic basalt, forming what may be called the *south-east limb* of the hill.

35, A bed of porphyritic basalt under Duddingston Churchyard.

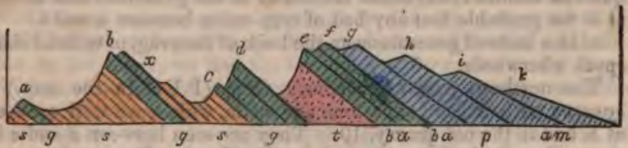
The *south limb* C, the portions of the hill surrounding the *apex* A, and a thick bed lying under the crag 18, 19, 20, are of traptuff. The bed D covers this traptuff as a cap.

E, Dunsapy hill seems a detached portion of the three eastmost beds of the north limb B, as indicated by the dotted lines.

The relative positions of these rocks, however, will be better understood from the *Section* No. I., which corresponds to the line *c d* on the map, and represents the interior of the hill, as it would be seen if laid open by a vertical section.

In this section, the greenstone and basalt and porphyry are marked by cross lines at right angles to the plane of the beds; the sandstone and shale by parallel lines in the direction of the beds; the amygdaloids by cross lines and dots; and the traptuff by dots. But, to prevent mistakes, letters of reference are placed below, viz.—*s*, sandstone and shale; *g*, greenstone; *t*, traptuff; *p*, porphyry; *ba*, basalt; *am*, amygdaloid.

FIGURE 1.



DESCRIPTION OF THE ROCKS.

a, St Leonard's Crag.—This is well exposed at Heriot's Mount. It is a blue porphyritic greenstone, with embedded crystals of felspar, and grains or crystals of augite, which present themselves as small angular black spots. This rock has sandstone above it at some parts, but at others is bare; and it rests on sandstone and shale. The greenstone is about fifteen feet thick at Heriot's Mount. It is blue in the middle; but assumes a brown and earthy appearance both above and below. The rocks here dip to the east at an angle of 15° or 20°; farther on towards the hill, (at *a* in the map,) they dip to the north; at 3, the Echoing Rock, they dip to the north-east; and at 4, Samson's Ribs, they swell out to a thickness of 80 or 100 feet, retaining the north-east dip. This rock passes under the Crags and Arthur's Seat. Specimens from the foundation of the house built close to the stile at St Leonard's, within the coal depot, leave no doubt on my mind that the rocks at Heriot's Mount and the Shepherd's House are the same bed with those of Samson's Ribs.

b, Salisbury Crag is a greenstone of the ordinary composition, consisting of dark green augite and whitish felspar; it is rather fine-grained, and contains a very few scattered crystals of felspar and grains of pyrites. It forms a fine bold precipice 80 feet thick at 6, but thins off towards its south extremity, (7 in the map.) Where it approaches the sandstone on which it rests, it invariably loses its crystalline texture, and becomes red and earthy. The discoloration extends about three feet from the junction. The bluish-grey colour of the greenstone first becomes paler; it next assumes a brown tint; and at the junction the brown deepens into a brick red, and the rock becomes compact. The sandstone is equally affected, becoming harder, and changing its white colour to red. The two rocks, in fact, are so assimilated at the junction, that it is difficult, in some cases, to trace the line of separation, or distinguish the one from the other. The general dip of the crag, and the sandstone above and below it, is to the east.

Salisbury Crag is divided from St Leonard's by strata of sandstone, shale, and clay ironstone, probably 300 feet thick, occupying the space from *a* to *b* in the section. They are covered by debris, consisting of fragments of the greenstone; but the upper beds may be seen on the path at the foot of the crag, and the lower in the quarries behind the Dumbie House, or in the garden of that house. It is not probable that any bed of trap exists between *a* and *b*.

x, Is a mass of greenstone on the back of the crag, of which I shall speak afterwards.

The northern part of Salisbury Crag (F F G in the map,) is covered with beds of sandstone and shale, which are well exposed at 5, and in the old quarry, 10. They are seen between *x* and *c* in the section, the hollow under *c* being the Hunting Bog. *x*, Is a mass of greenstone reposing on the crag, of which I shall speak afterwards. These beds pass under Bog Crag. They had once extended over the whole crag, for a patch exists at the edge of the precipice, southward from 9 in the map. A large portion, however, had been washed away, leaving the back of the greenstone exposed.

c, Bog Crag.—The lower part of this crag is a greenstone porphyry, of a striking appearance. It has a base of greenstone, which is beautifully spotted with crystals of felspar. It may be seen (at 16 in the map) nearly on a level with the Hunting Bog. It rises at it proceeds southward towards the *apex*, and at 17 (in the map) is covered by another bed of greenstone, which is of a dark green colour, with less white felspar, but many embedded crystals of this mineral nearly of the colour of the hornblende. Blackish crystals or grains of augite are also thinly distributed through it. This upper rock has a considerable resemblance to that of Samson's Ribs. Bog Crag, at its south end, forms three swells or knolls, the tops of which are probably 150 feet above the Hunting Bog.

The southmost knoll contains a mass of stratified traptuff, about six feet thick in its lower part. South

I consider Girnal Crag on the side of the hill (31, 32, in the map,) as a continuation of Bog Crag. The rocks have a close resemblance in texture and appearance, and there is a correspondence in their position. Girnal Crag, like Bog Crag, rests on sandstone, and is the eastmost rock in the hill which does so.

d, Well Crag rests on Bog Crag, and there is probably a transition from the one rock to the other. It is a compact greenstone of blackish-green colour, containing a few crystals of felspar, and nodules of carbonate of lime, coated with green earth. Boué describes it as an earthy dolerite, containing much felspar. The cavities are more numerous in the lower part, so as to give the rock an amygdaloidal character. On its upper side also it passes into an amygdaloid, which is greenish-grey at the well, but becomes red at the head, apparently from the proximity of the red traptuff.

The hollow betwixt this Crag and the next forms St Anthony's valley, a beautiful sequestered glen, extending southward from the chapel to the base of the apex.

The bed *t*, which separates *d* and *e*, is from 100 to 150 feet in thickness. It is only partially seen, in consequence of the surface being much covered with debris and herbage. At St Anthony's Well we can trace, through openings in the soil, a depth of 15 or 20 feet of greenish-grey traptuff at the bottom of the bed; and farther up the valley, we find the same tuff well exposed to the depth of 30 or 40 feet, under the blue columnar basalt *e*, which forms the next rock in the series. We have thus traptuff both at the top and bottom of the bed. It consists of fragments, generally angular, of various species of trap, embedded in a paste of the same substance in a decomposed or comminuted state. It is in some places loosely, in others firmly aggregated, and is disposed in pretty regular strata, which are often divided into thin laminæ. This rock will be more fully described hereafter.

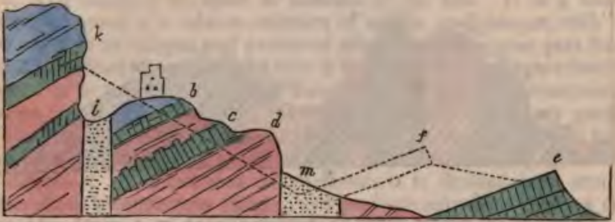
The vertical precipice on the east side of St Anthony's Chapel is an amygdaloid. It has a brown or reddish-grey base, which is softer than greenstone: the cells are round, and not very numerous: they are generally from the size of a pin-head to a hazel-nut, and filled with various sparry minerals, which are often coated with green earth. The base presents concretions of a roundish shape, from one or two, to six or eight inches in diameter. These are sometimes in contact with one another; sometimes enveloped in looser matter like traptuff, but which is perhaps the same rock in a disintegrated state. It resembles in structure those greenstones where we find rounded nuclei of solid rock enveloped in concentric coats of the same substance: masses of some of the other traps of the hill are embedded in it. The basalt found in the front of the crag, and the displacements which have taken place in the beds here, indicate that this amygdaloid is most probably the prolongation of the bed which is found in the middle of the reddish basalt, and above the blue columnar basalt, farther south.

efg, Are three beds of basalt, (19, 20, 21, 22, 23, 24, in the map,) which can be examined with greatest advantage near the head of the valley. The lowest, *e*, is a blue basalt, a fine granular mixture of black augite and white felspar. It is in irregular columns, from one to three feet in diameter. The bed is from 10 to 30 or 40 feet thick, and rests on the stratified traptuff. Above it is a bed of ferruginous basalt, *f*, of a chocolate colour, with a few red grains, consisting probably of decomposed augite. It is of variable thickness, much fissured, and in some parts imperfectly columnar. A bed of reddish-grey amygdaloid separates this bed from the preceding, which is thin at the south end, and sometimes wanting, but swells out to a considerable depth at the north end. Above the reddish basalt is a bed of blue basalt, *g*, probably 50 feet thick. Its texture and colour vary considerably: the lower part is generally blue and compact; the upper has often a greenish tint, from a minute mixture of grains of olivine. It is usually in large irregular columns, from one to two yards in breadth, which seem to be composed of tables from six inches to two feet thick, placed one upon another. These three beds can be traced to the north side of the hill, but with occasional interruptions. They are all composed of augite and felspar, and, though they sometimes assume the appearance of greenstone, belong to the basaltic series. The last-named basalt, in its upper part, assumes first a grey, and then a reddish colour; and passes into a porphyry, *h*, with a red hard tenacious base of felspar, in which are embedded numerous grains and distinct crystals of felspar, of the same colour, or a little lighter. It also contains a few crystals of a brown colour, which are probably decomposed augite. This is covered by two beds (or perhaps more) of amygdaloid, *i k*, which are seen towards the east end of the hill. The base of these rocks is of various shades of red, brown, blue, or purple, and generally porphyritic, presenting a few crystals of felspar. The amygdaloidal cells seldom reach one inch in diameter: they are of irregular forms, but rarely angular, and sometimes so numerous as to occupy half the bulk of the rock. When the zeolites, calcareous spars, and other minerals which fill them, have wasted away by exposure to the air, the rock resumes the appearance of what it no doubt originally was, a cellular lava.

The horizontal space from Bog Crag, *c*, to the most eastern part of the hill where the rock is visible, is probably about 3000 feet. The general dip of the beds is nearly east; that of the green porphyry of Bog Crag is 23° to N. 80° E. Elsewhere it does not admit of precise determination; but if we assume the average dip to be 20°, the entire thickness of the trap beds will be 1000 feet. Most of the beds seem to be thicker below than at the top or outcrop, and at the north end of the hill than at the south. The arrangement of the rocks, as seen from the Duke's Walk, or the road to Lochend, forcibly suggests this conclusion.

The small isolated crag (12 in the map,) at the north side of the hill, is a part of Well Crag (13, 14, 15,) as the nature of the rock shows. It appears to me that this small crag has been detached from Well Crag, and moved into its present position in consequence of some subterranean concussion producing a *fault* or dislocation, which has also affected the hillock supporting the ruins of St Anthony's Chapel; or the change of place might result from the erosion of the softer beds on which the rocks rested, by the long-continued action of a tide or current of water. The diagram below will render this intelligible. The view is from the north.

FIG. 2.



k i, The crag at the back of the chapel, about 60 feet high.

b, The chapel, with disturbed masses of basalt below and around it.

c, The columnar basalt below the chapel, in a distinct bed.

d, A tuffaceous amygdaloid, to be described afterwards.

e, The small detached crag.

f, Well Crag, of which *e* once formed the extreme northern part, though now broken off and separated from it. It is marked by dotted lines, because it is in the background, farther off from the spectator.

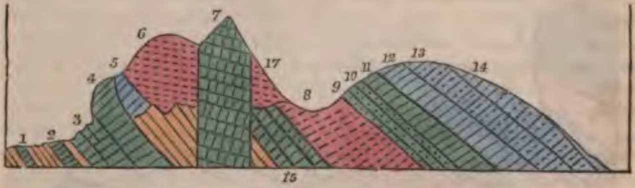
A dotted line from the precipice *k* to *m*, marks the position of the talus of gravel and soil immediately beyond *b c d*, showing how the hillock projects beyond it, in consequence of having slid forward. The oblique parallel lines under *b* and *d* do not represent strata, for the rock is unstratified, but indicate the general dip of the beds of the hill.

The vertical line at *i*, under the precipice *k*, marks what I conceive to be the first fracture: the dislocation here is probably 60 feet of downcast. The second is perhaps under *d*, and may amount to 30 or 40 feet more. The rock *e*, is 80 or 100 feet lower than *f*, of which it once formed a part, and advances 150 feet farther to the westward. It had also slid about 80 or 100 feet northward, leaving the open space through which the footpath passes. The motion had been downward, and in a north-west direction; and it probably left vacuities under *i* and *m*, which were filled up with debris and soil. There are portions of two beds of basalt embedded in the precipice *k i*, corresponding to the two beds *b c*, under the chapel.

The northern limb of the hill, to a considerable distance eastward and southward from the chapel, has also been disturbed by *faults;* for the beds there appear broken, displaced, and in some cases commingled, and the surface is indented by irregular depressions.

FIG. 3.

SOUTHERN PART OF ARTHUR'S SEAT.



This section passes through Arthur's Seat in a north-east and south-west direction, from a point near 3 to 27. (See the map.)

1, The Echoing Rock, which is a continuation of St Leonard's Crag, and terminates in Samson's Ribs. It rests on and is covered by sandstone.

2, The south extremity of Salisbury Crag, near the Powder House. It is also covered by sandstone, a small portion of which is seen adhering to the back of it.

3, There are two or rather three portions of rock above this, which seem to be remnants of beds resting conformably on No. 2. They are of greenstone. The first is probably the upper portion of Salisbury Crag; and behind them southward is found a reddish porphyry.

4, A vertical precipice about 80 feet high. It is of compact earthy greenstone, and has embedded in it masses of different greenstones, of all sizes up to two feet in diameter. They are generally angular, often crystalline in texture, and may be seen projecting in high relief from the enveloping rock, while some have fallen out and left vacuities. At the bottom is found a greenish amygdaloid, enclosing nodules of calcareous spar. When the south end of this greenstone is examined, a reddish porphyry, which covers it, is found passing round its extremity, and apparently underlying it; and the position of the greenstone suggests the idea that the rock is a thin vertical mass like a vein. It may be such;

but in the absence of precise data, I have placed it conformably to the beds of Salisbury Crags and Samson's Ribs.

5, A reddish porphyry, which contains fragments of other rocks, and passes into the traptuff, 6. Its lower part is of a pale grey colour.

6, 17, The traptuff which covers the upper part of the hill. It consists of comminuted or decomposed trap, forming a sort of paste, in which smaller and larger fragments are embedded. The fragments are generally angular, so that the rock is properly a breccia. It is of two descriptions—one greenish-grey, which is lowest—the other red or brown, which covers it. There is a considerable quantity of carbonate of lime diffused through the tuff. It seems to have passed in by infiltration, filling the crevices and minute vacuities, and serving partly as a cement.

7, The basalt of the *apex* or summit of the hill. It is a blue rock, composed of a minute mixture of augite and felspar, with a few crystals of felspar and grains of olivine. The upper part has a red tint, from the oxidulated iron it contains, and presents minute specks of a bright red, which I believe consist of decomposed augite. "It is," says Boué, "a basalt identical with many parts of the ancient coulées (currents of lava) of Auvergne." The inferior or blue rock is in pretty regular columns, from 1½ to 3 feet in diameter. The red rock which covers it is divided into small concretions by numerous fissures, and presents only faint vestiges of the columnar structure. In the blue columnar rock the seams between one row of columns and another, convey an idea of strata dipping to the north-east; but this structure is undoubtedly concretionary, and does not indicate that the basalt was deposited in successive portions. I have represented the rock as constituting a long prism or columnar mass, penetrating downwards through the inferior rocks of the hill. This, of course, is merely a conjecture based on facts and inferences to be stated afterwards. The horizontal length of the visible part exceeds 500 feet, the breadth is about 400.

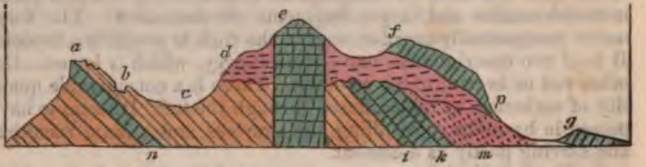
8, The traptuff found on the east side of St Anthony's valley, already described.

9, The blue, and 10, the red basalt of St Anthony's Crags, divided by a thin bed of amygdaloid. These basalts should have been cross-hatched, like 11 and 12. They are marked *e* and *f* in Fig. 1.

11, The upper blue basalt (*g* in Fig. 1,) passing into a brown porphyry, 12, and covered by amygdaloids, 13, 14.

Bog Crag and Well Crag are shown above, 15. (See *c*, *d*, Fig. 1.) I assume that they advance under the traptuff, till they are cut off by the basalt of the *apex;* but they probably terminate where they join the traptuff (at 15 in the map.) Bog Crag, and Girnal Crag, which is its south extremity at the opposite side of the hill, both rest on sandstone; and I therefore infer that the sandstone extends through the base of the hill. In this situation, it will of course be pierced by the column of basalt which constitutes the apex, if that column reaches downward in the manner I have assumed.

Fig. 4.

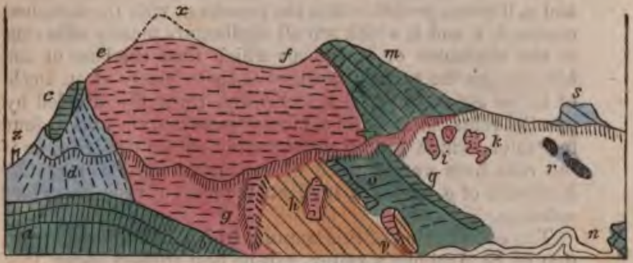


This section extends through the hill in a north-west and south-east direction, along the line *e f* in the map. It is introduced chiefly to show the position of the bed of basalt *f*, which caps the south-east limb of the hill. It is marked D in the map.

a, Salisbury Crags, the north-west side.
b, The old sandstone quarry on the back of the crags.
c, The Hunting Bog.
d, The traptuff near the head of Well Crag.
e, The apex.
f, A large bed of porphyritic basalt. This rock, which is of a bluish-black colour and crystalline aspect, contains embedded crystals of Labrador felspar and augite, and grains of olivine. It is columnar, and the surface on which it rests dips rapidly to the south-east, so that the lower part hangs, as it were, on the slope of the hill. The columns are of various sizes, and also incline to the south-east. Its extreme thickness is probably 150 feet, its length probably 600 feet, and its breadth 500. It rests on the traptuff, which is distinctly seen under it on all sides except the east, where there is a thick covering of soil. Portions of it are found on the declivity which overlooks Duddingston, adhering to the tuff, where the surface of the latter descends at an angle of 40° or 50°. The bed *g*, under Duddingstone churchyard consists of the same rock.
i k, Girnal Crag and Loch Crag, which are the south extremities of Bog Crag and Well Crag. I have assumed that the traptuff which covers Well Crag on the north side of the hill, (*t*, Fig. 1, and No. 8, Fig. 3,) also exists here at *m*, though the covering of turf conceals it. It is at least partially stratified, and in this respect differs from the overlying traptuff which surrounds the apex, and passes under *f*.

The sandstone which occupies the space from *n* to *i*, appears of great extent here; but it must be kept in mind, that the section crosses the planes of the beds between *c* and *i* at a very oblique angle, so that the actual thickness bears a small proportion to the surface exhibited. The sedimentary beds, however, between *a* and *d*, are probably from 150 to 200 feet thick.

Fig. 5.



This Figure represents a *View* of the south side of the hill, as it would be seen by a spectator stationed half a mile southward. It is sketched, however, hypothetically.

a b, The eminence of which Samson's Ribs constitute the south face. It is of blue porphyritic greenstone, containing crystals of felspar and augite: *a*, the columns. The upper part of the rock exhibits a certain change of character. First, it loses its columnar structure, but retains its blue colour; and next, it assumes a reddish tint. The two varieties may be distinguished on the top, and descend at *b* nearly to the footpath. This eminence projects 100 feet or more from the body of the hill towards the spectator. The hollow behind it, indicates that the bed dips to the north-east or north-north-east.

c, The crag of compact greenstone 80 feet high, above the Powder House *z*. It is No. 4, in Fig. 3.

d, A bed of porphyry (marked 5 in Fig. 3.) It is of a dark brown colour towards *z*, but changes gradually to a brick red as we proceed eastward: it is then found to envelope a few fragments of other rocks, which become more numerous till at last it passes into the traptuff *e f*. This porphyry can be traced over the head of the crag *c*, and it seems to descend to Samson's hillock, though a covering of soil conceals the junction. It contains long crystals of felspar, with small red grains probably of decomposed augite, and a few round cavities filled with spar.

e f, The bed of traptuff which constitutes the principal mass of the south limb of the hill. It is perhaps 400 feet thick, or more. Its lower visible margin is marked by the uneven shaded line passing eastward from *d*; but a portion projects downward from the mass at *g*, and another is seen protruding through the soil at *h*. As a small part of it is also found resting on the greenstone near *b*, I conclude that it occupies the whole or greater part of the surface between *d* and *g*. From the manner in which it meets the greenstone crags *o* and *q*, it seems probable that the process *g*, with the detached masses *h*, *i*, and *k*, which are all similar, are merely adhering to the sandstone or other beds which form the base of the hill, though the surface declines at these places at an angle of 45° or 50°. Between *d* and *g*, the traptuff is divided by parallel rents, so as to form tabular masses from two to four feet thick, which repose conformably on the declivity, as if the rock here were formed of concentric layers or coats.[*] Eastward of *g*, however, it affects the form of rude imperfect columns.

The composition of this traptuff, which differs widely from that of St Anthony's valley, can be best studied along this side of the hill. It is of various shades of red or brown; but the prevailing colour approaches to brick red. The base consists of comminuted matter like fine sand or clay, with which is generally mixed small fragments apparently of all the traps in the hill, and larger embedded masses of various sizes up to cubes of five or six feet. They are almost always angular. They project in bold relief when the base is soft; but when it is hard, they are only distinguishable by their colour and texture. Some of these masses are of sandstone: two may be seen near *g*, of considerable size; they have changed their colour, are very hard, and have acquired the glimmering lustre of quartz rock, like sandstone embedded in trap. A large proportion of the enclosed fragments here consist of a porphyry like *d*, on which the tuff reposes; there are also apparent fragments of Bog Crag and Well Crag, of Samson's Ribs, of the porphyries and amygdaloids of the north limb;[†] and there is one mass on the footpath at *g*, which is easily recognised as belonging to the black porphyry *m*. I have seen none of the dark blue basalt of the apex; but there are many grey compact fragments, which may consist of the same rock altered. There are occasionally pieces of limestone; and lastly, there are fragments which enclose other fragments, that is, pieces of an older tuff enclosed in a newer.

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[*] It is perhaps worth notice. that the deposits of lapilli and volcanic tuffs, in active volcanoes, often arrange themselves in beds from one to four feet thick.—LEONHARD GRUNDZUGE *der Geologie*, p. 143 and 263.

[†] There is a mass of bluish-green porphyry seen in the soil above Samson's Ribs, about five or six yards broad and long. It is probably derived from Bog Crag. That it might be lifted up by volcanic explosion and lodged here, is quite credible. Elie de Beaumont mentions moved masses of tertiary rocks 50 feet in diameter, embedded in the trachytic conglomerates of the Cantal.—*Memoires pour servir à une Description Geologique de la France*, Tom. ii. p. 291.

m, The black porphyritic basalt, marked *f* in Sect. 4, and D in the map. It has been already described.

n, A rock perfectly similar to *m*, under Duddingston Churchyard. It is washed by the loch, a small portion of which appears in the Figure.

o, *p*, Girnal Crag, of porphyritic greenstone, with a breach in the middle, through which the footway passes. Sandstone, dipping at a pretty high angle, may be seen under both parts. How far it extends, I am unable to say: its western boundary is therefore to be considered as conjectural. The lower end *p*, has a portion of sandstone on its back.

q, Loch Crag, a compact greenstone. In its upper side it becomes a reddish amygdaloid, the change being similar to what takes place in Well Crag, of which I consider it a prolongation.* This amygdaloid passes into one of a bluish-grey colour, but more cellular, and both contain much carbonate of lime. A few yards farther east, many blocks of a white or brown splintery silicious limestone are found in the soil, and probably belong to a bed of this species of rock, which is concealed by the turf. The space between *o* and *q* is covered with soil and debris: I infer that it is occupied by a greenstone, like that which separates Well Crag from Bog Crag, with perhaps some sandstone, as the mass of this substance on the back of *p* indicates.

r, Portions of an amygdaloid, *in situ*, present themselves on the acclivity, 20 or 30 yards from the wall. The base is generally dark and firm, the cells extremely numerous. From its position, it ought to be a prolongation of the bed which lies under the second basalt, in the north limb of the hill, (21, 22, in the map,) but it more resembles the bed 27, 28.

s, Dunsapy, (E in the map,) a hillock about 100 or 120 feet in height, which will be described afterwards.

x, The apex.

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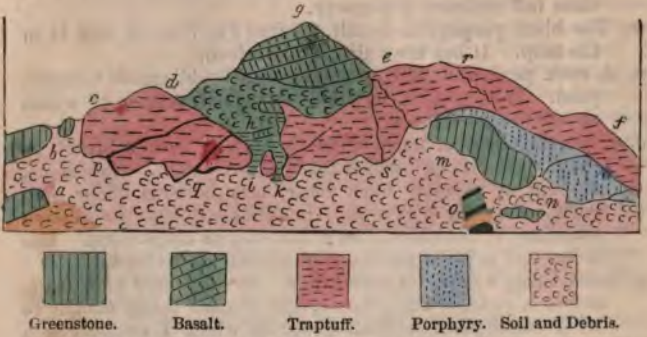
* This was also the opinion of Boué.—*Essai Geologique*, p. 191.

Fig. 6.



View of the west front of Arthur's Seat, under and near the apex, taken from Salisbury Crags.

a, The head of Bog Crag. Porphyritic greenstone.

b, The head of Well Crag. Compact greenstone.

c, *d*, *e*, *f*, The great formation of traptuff, which surrounds the apex.

g, The apex, of columnar basalt in *apparent* beds, dipping N. E.

h, A recess or hollow in the envelope of traptuff, which invests the basalt on the south side towards *f*, but is wanting in the space from *h* to *d*. On the right of *h*, and above it, the basalt is seen projecting a few yards beyond the mantle of traptuff: from this to *d*, the surface is covered with debris or soil, except at a few points where the basalt protrudes. From *h* downward there is a gap or deep indentation, descending to *i k*, about 80 feet long, which is divided into two at the foot by a cone of traptuff.

s, A narrow vein.

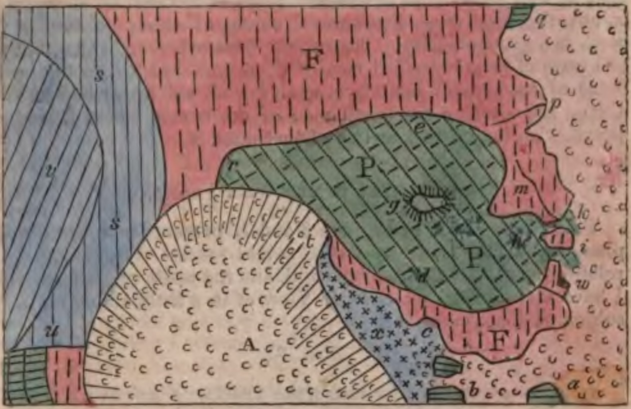
m, A precipice of compact greenstone, 80 feet high, above the Powder House, (*c* in Fig. 5, and 4 in Fig. 3.)

n, The red porphyry which passes into the traptuff, (*d* in Fig. 5.) A separate portion, apparently of the same porphyry, is seen on the left of *n*.

o, Two portions of greenstone, apparently the remnants of one bed or two. They are near the south end of Salisbury Crag greenstone, and in a conformable position, (No. 3, Fig. 3.)

The position of these different rocks will be understood from the subjoined ground-plan.

FIG. 7.



This map, or ground-plan, exhibits the form of the apex PP, on the horizontal plane, and the position of the traptuff FF, which surrounds it.

a, The head of Bog Crag, as before.
b, The head of Well Crag, as before.
r, *d*, *h*, *e*, The visible boundaries of the apex of basalt; *g*, the summit. The letters *c*, *d*, *h*, *g*, *e*, correspond in position with the same letters in the preceding Figure.
t, *c*, *w*, *i k*, *p*, The outer margin of the traptuff on the north and west sides; *i* and *k* mark the deep indentation noticed before.
q, The crag marked *m* in Fig. 6.
s, *s*, *v*, Greyish greenstones, seen at a few points.
u, The basalts 9, 10, 11, in Section 3, with the traptuff below them.
A, The head of St Anthony's valley, deeply covered with soil.
x, An amygdaloid, into which the underlying greenstone, *a*, of Well Crag, passes.
m and *p*, and *w*, Basalt veins: *p* is marked *s* in Fig. 6.

It will be seen, from this miniature map or ground-plan, that the traptuff invests the basalt all round like a sheath, except between *t* and *r*, a space of about 60 or 70 yards. By comparing the above Figure with the preceding one, and with the section Fig. 3, a complete idea will be obtained of the position of this envelope. That section passes through the apex in the direction *q*, *g*, A; and the portion of traptuff marked 17 there, is that marked *t* here.

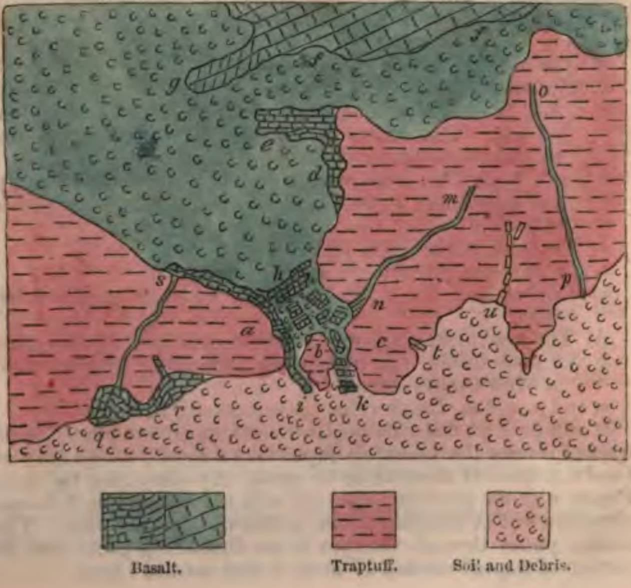
On the north side, opposite the crag *a*, the envelope of traptuff is probably 50 yards thick. The colour is brick-red; it has imparted the same tint to the head of Well Crag, *b*, which is only four or five yards from it, and still more to the cellular amygdaloid *x*, covering that crag, the natural colour of which, as seen at the well, is a greenish-grey. From this circumstance, I infer that the red traptuff once extended two or three hundred feet to the northward of its present boundary, covering all the upper end of Well Crag, and coating the portion *t r* of the basalt, which is now exposed, with only a foot or two of turf upon it.

THE VEINS IN THE WEST FRONT.

This recess *h, i, k*, in Figures 6 and 7, presents some interesting phenomena, and seems to me to reveal secrets of importance, in relation to the structure of the hill, and the mode of its formation. I have therefore given another View of it, a little enlarged, in the subjoined Figure.

FIG. 8.

VIEW OF A PORTION OF THE WEST FRONT OF ARTHUR'S SEAT, FROM THE BACK OF SALISBURY CRAGS.



In this View of the Recess, and adjoining parts, the eye is supposed to look down at an angle of 45°, that is, nearly at right angles to the declivity. On clambering up amidst the debris at *k*, as soon as we come to the opening between *b* and *c*, we find ourselves standing on columns of basalt, which are of small diameter, but regular, and disposed across the opening, as shown in the Figure. It is in fact a vein of basalt. They are also found between *a* and *b*. They continue up as far as a projecting portion of the same rock *h*, but covered at intervals with debris ; and in other cases, portions of a crumbling rock present themselves protruding from below, as if they formed the base on which the basalt rests. They are of the nature of traptuff, and envelope a few small pieces of the basalt. A sharp projecting ridge divides the vein into two ; it is continued downwards, and terminates in the cone of traptuff *b*. The branch of the vein which passes through the opening between *b* and *c*, may be traced to *k*, about 20 feet outside of the gap. The south wall of the vein, down to *k*, consists of traptuff, from 20 to 40 feet high : a great part of it is coated with fragments of the columns of basalt adhering to the traptuff : they sometimes present their ends to the spectator, sometimes their sides. In the two breaches, however, between *a* and *b*, and between *b* and *c*, the position of the columns is rather more uniform. They lie across the vein, like the prisms of our trap dikes, and the dikes of Monte Somma and other volcanic cones. The floor of the vein from *i* to *h*, is very steep, having an inclination probably of 50° or 55°. This summary account seemed necessary to prepare the reader for a more detailed description.

a, Part of the western and northern envelope of traptuff, (*w*, *c*, Fig. 7.)

c, Part of the western and southern envelope, (between *k* and *p*, Fig. 7.)

b, A cone of traptuff, once continuous unquestionably with *a* and *c*, and still probably connected with them below. It is about 30 feet high, and 25 feet broad at the base. The depth of the breach or aperture between *b* and *c* is about 25 feet measured from the top of *b*, or 35 measured from the top of *c*. Its width at the bottom is eight or ten feet. It is paved with basalt columns, lying on their sides.

The length from *h* to *k* is about 100 feet ; the breadth of the recess, in the direction *a n*, about 40 feet. But, except at *h*, the basalt seems rather to have been distributed through this space in several veins, occasionally communicating, than to have filled it. The depth of the basalt, judging from fragments adhering to the traptuff walls, may have been 20 feet.

m, *n*, Is another vein of basalt, which joins the first at the south side of the recess. It is from five to ten feet broad, and can be traced for 100 feet or more upwards and southwards. It consists of columns of the blue basalt of the apex, lying transversely; its depth must have been at least eight or ten feet, and the columns can be seen at some parts distinctly resting on the traptuff. A small portion, however, only remains, the outer wall of tuff which protected them being removed along almost the whole course of the vein, and with it a great portion of the basalt. There is no trace of it on the top of the traptuff crag, and it must therefore have burst through somewhere about *m*, but the spot being inaccessible, cannot be examined.

A portion of the basalt *h*, is found running close along the inside of the wall of traptuff *a*. It is shown in the diagram, extending from *s* to the breach between *a* and *b*, and down to *i*, 30 feet beyond it. It seems to pass almost vertically downward, leaving the wall of traptuff at *a*, not more than 10 or 12 feet thick. It becomes light in the colour and earthy near the tuff, while the latter becomes hard and compact, and assumes the appearance of an earthy greenstone. The component parts of the tuff seem fused together, though not completely homogeneous in aspect, and it is pervaded by crystallized carbonate of lime, in threads or shining plates. The surface of the hardened traptuff is in some parts coated with the same substance, and beautifully and regularly grooved. The grooves are nearly horizontal, but decline a little towards the opening in the tuff, and are exactly such as would be formed by the friction of masses moving in the direction of the coulée *h, i*. There are others transverse to these, and also horizontal, showing that masses of the traptuff had moved on each other. There is a block near the entrance *i*, two feet broad, one side of which is basalt, and the other traptuff, exhibiting a transition from one to the other, without any visible line of distinction.

o, p, Is another vein of basalt, from two to three feet broad, and probably 130 feet long. It is very straight, and may be traced along the steep uneven surface of the traptuff, from a point *o*, within 50 feet of the basalt of the apex, to *p*, where it is lost under the debris. Its texture is not crystalline, but earthy, a peculiarity generally observed in narrow veins, the matter of which having cooled rapidly, owing to the smallness of its mass, was not in a condition to assume a crystalline arrangement. This vein is about 20 yards northward of a gutter, cut in the soil by the rains, near the steep path to the summit.

q, r, About 10 yards on the left of the opening *i*, the basalt is found protruding from under the traptuff, in the form indicated by *q, r*. These two portions occupy a horizontal space of 40 or 50 feet: below, they are covered by the soil, and their greatest visible depth is about 10 feet. There is an appearance of a vein above *q*, which I have supposed to pass upward to *s*; but, owing to the steepness of the escarpment, I could not fully examine it. There is also an appearance of a small vein above *r*, which perhaps joins the other. The mass *q*, *r*, is probably a horizontal vein, that is, a portion of basalt which had penetrated through a horizontal fissure in the traptuff, as the others, *i* and *k*, and *m*, *n*, and *o*, *p*, have penetrated through vertical fissures. It is analogous to the trap beds found intercalated among the sedimentary rocks, in a conformable position. When the basalt forced its way through the tuff here, it would almost necessarily produce vertical rents; and one of these being filled with the liquid basalt, might form the vein *q*, *s*.

There are probably other veins which have escaped my observation. One about a foot broad, may be seen in the traptuff at *k*, passing off from the coulée,* which descends from the recess; and towards *p*, in Fig. 6, there is a basaltic mass, apparently composed of a congeries of small globes of basalt, placed amidst decomposed matter of the same kind. It may be analogous to *q*, *r*. There are also, at various parts of the west front, what have the appearance of veins of red traptuff in the grey. These may be considered as accidental hollows or fissures in the grey tuff filled by the red.

e, *d*, Portions of the basalt of the apex, protruding from below the cover of traptuff. Specimens, taken close to the tuff, are paler in the colour, and have the appearance of a compact earthy greenstone. This basalt, with its mantle of traptuff, projects 30 or 40 feet outward from the part of the surface under *g*. Betwixt *g* and *h*, and farther on to the left, the traptuff, with the outer portion of the basalt, has been removed by diluvial agency. This, however, is but a small part of the denudation which the rocks here have undergone. *g*, Is a portion of the basalt of the apex.

The basalt at *e*, and at *d* too, presents a semblance of horizontal strata. This, with the aspect of the masses seen at *h*, shows that the appearance of beds dipping to the north-east in the apex, (*g*, Fig. 6,) does not indicate the deposition of the rock in successive portions, laid one above another, but is merely concretionary, depending probably on the direction in which the cooling influences were propagated through it. Is it not probable also, that the ironshot character of the upper part of the column, was an alteration induced after the rock was formed, by the penetration of matter in a liquid or gaseous shape?

At *t*, a mass of sandstone, five or six feet long, is embedded in the traptuff; and at *u*, portions of sandstone, one or two feet broad, stretch upwards vertically for 30 or 40 feet, branching into two at the top. The sandstone has, as usual, the hardness of quartz rock.

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* This term properly signifies, a current of lava flowing from a volcano in the open air. Finding it convenient, however, I have applied it loosely to veins like this, which were injected among pre-existing rocks.

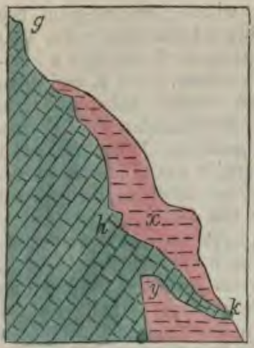

Fig. 9, Is an ideal vertical section from *h*, to the heart of the apex, (*g*, Fig. 7.)

g, The basalt of the apex.
x, *y*, The mantle of traptuff.
h, *h*, The vein, as seen in connexion with the traptuff on its south side.

If the Section had represented the vein in connexion with the traptuff on its north side, the latter would have been much thinner. I have assumed the existence of the traptuff at *y*, extending far inward under the basalt, though this may admit of doubt.

In the recess *h*, *i*, *k*, (Fig. 8,) we have, what we seldom see, a vein in connexion with the parent mass. We may suppose that, when the traptuff was deposited, an orifice or chimney existed, or was opened in it, and occupied the space where the central mass of basalt is now placed, (*e*, Fig. 4. ;) that it was filled with basalt still in a liquid state, a portion of which, under the pressure of a column 250 or 300 feet in height, forced a passage at *h*, (Fig. 9,) through the mass of traptuff, which then perhaps extended much farther to the westward, and was as high as the present summit. The passage might be at first nearly horizontal, and perhaps assumed an inclined appearance, in consequence of the waste of the exterior and lower parts. The eruption would fracture and disturb the tuff on this side, and render it so much the more easy for tides or currents to sweep portions of it away, and leave the apex in the half-denuded state in which it now appears. All the veins are evidently processes, passing laterally through the traptuff, and not fissures reaching to an indefinite depth below. The traptuff can be seen *under* the vein *m n*, at some parts of its course: it also protrudes through the floor of the great vein, and it distinctly underlies the lower and outer extremity at *k*. The appearance of the vein *m n*, suggests the idea of a narrow canal cut in the tuff, the outer side of which has for the greater part been broken off.

In the traptuff on the south side of the apex, I have not observed a single vein; but that mass is of great breadth, and the southern escarpment, (Fig. 5,) where alone we have a good opportunity of examining it, is from 500 to 800 feet distant from the central column of the apex. The liquid basalt may have pierced the traptuff on the west side preferably, because, being thin there, it presented less resistance; or it may have sent out similar veins on all sides; but, having penetrated only a short distance into the tuff, we do not see them, except where the outer portions of the envelope have been removed.

The traptuff, as already observed, contains much carbonate of lime. This had passed into it, posterior to its deposition, by slow and gradual infiltration, and, along with oxide of iron, has no doubt served to give it solidity, as Boué remarks.* The peperites, or volcanic tuffs of Auvergne, are often agglutinated into a firm rock by the same means, and penetrated by dikes, or veins of basalt, in the same way. Examples are found in the Puy Piquette, in the mountain of Gergovia, and elsewhere in Auvergne.†

The veins prove that the traptuff, at least the lower portion of it, existed before the basalt, since the walls of a vein must be older than the matter which they serve to confine.

The traptuff seems to consist of several deposits: the order of succession in the lower part is best seen in St Anthony's valley: we have here, 1. A greenish-grey stratified traptuff, displaying in some parts a finely laminated structure. This rests on Well Crag, and a small portion of it is seen at the well. 2. In its upper part, the stratified tuff passes into a pseudo-amygdaloid, which assumes various appearances. Sometimes it is a congeries of minute fragments of trap, united by carbonate of lime: sometimes it is a paste of decomposed or finely comminuted trap, (such as constitutes the stratified tuff,) with numerous small rounded cells, which are filled with crystallized or uncrystallized carbonate of lime, and sometimes coated with green earth. This had apparently been formed in the same way as the proper amygdaloids. It may be seen in the prominent rock under St Anthony's Chapel near the well, at various places on the east side of St Anthony's valley, and under the apex on the west front of the hill, about *q*, Fig. 6. 3. In its upper part it passes into the greenish-grey stratified tuff again, which is well exposed under the blue basalt on the east side of the valley, (at *a*, Fig. 15.) It is composed partly of comminuted matter, like clay; partly of angular fragments, from the size of a bean downwards, united by more finely divided matter, and occasionally enclosing pretty large angular blocks, which, however, are not so numerous as to prevent the rock from assuming the stratified structure. The grey traptuff on the west front, from *p* to the crag *m*, Fig. 6, consists chiefly of this species; but it displays only feeble traces of the stratified structure. As the pseudo-amygdaloid is found under it at *q*, I consider this tuff as corresponding to, and contemporaneous with, the upper portion in St Anthony's valley, which reposes on a similar rock. 4. The red traptuff is seen on the north side of the apex, from *p* round to *d*, Fig. 6; and on the south it appears near *e*, and extends over the whole southern slope from *r* to *f*, and down to the line where the rock disappears. This rock is distinguished from the preceding varieties by its brick-red colour, by the absence of visible trap veins, by the absence of stratification, and by its position in reference to the older rocks, which is unconformable and overlying; while the grey traptuff in St Anthony's valley is placed conformably among these rocks. There are varieties of traptuff intermediate between the red and the grey, which cannot be referred with certainty to the one or the other. Some of these, found on the west front, may be remnants of the proper red tuff, which perhaps once overlapped the grey, as a mantle, on all sides, but has been removed on this. Others may be varieties, originally existing in the grey, owing to local causes. The two kinds, though now and then intermingled, are sufficiently distinct on the great scale. The oblique lines under *e* and *r*, and that extending from *p* towards the apex, indicate the limits in a rough way. The tuff between *p* and *d*, closely resembles that between *r* and *f*.

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* *Essai Geologique sur l'Ecosse*, p. 268.

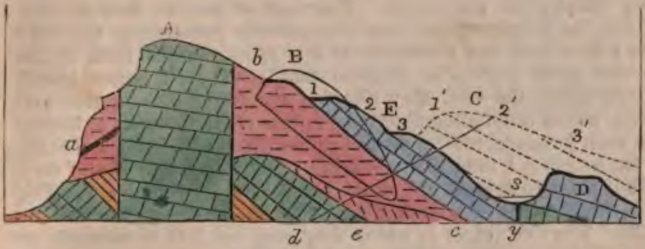
† Lecoq et Bouillet, *Vues et Coupes des principales Formations Geologiques du Puy de Dome*, Plates 3, 24, 25, 26, and 29. The veins in this last are of trachyte. See also Pp. 11, 21, 212, 214, of the descriptive letter-press.

Two general observations occur respecting the mass of traptuff as a whole. First, there are obscure indications in the lines which separate the red from the grey, and in the rents and marks of division seen on the west front, of something approaching to a symmetrical arrangement round the nucleus of basalt, as if in beds dipping away from it, and which may be the result, either of the manner in which its parts were successively deposited, or of disturbance from the protrusion of the basaltic nucleus. Secondly, the appearance of the traptuff along the south side, with the process *g* and pendicles *h*, *i*, *k*, (Fig. 5,) adhering to the steep declivity, are most consistent with the idea, that, when placed on the hill, it was in a very moveable state, (probably from being mixed with water,) and left free to accommodate itself to the inequalities of the surface, filling up hollows where they occurred, and lapping over declivities, in the manner of clay or earth dropped on a sloping bank in still water. These remarks are offered merely as loose conjectures, resting on data which are too equivocal to serve as a basis for positive conclusions.

At *e*, the junction of the basalt with the traptuff of the south limb, there is a mass of a peculiar character, just on the edge of the escarpment. It is about 25 feet broad, and 30 or 40 high. The traptuff next to this is of the usual kind,—a hard reddish paste, in which angular fragments of various rocks, of one, two, or three feet square, are thinly distributed. But in the mass in question, pieces of basalt, from one to six inches in diameter, constitute four-fifths of the whole; and just such a quantity of minute fragments is mixed with them, as suffices to unite them, aided probably by calcareous or silicious infiltrations. It is a true basaltic conglomerate, in which both base and nodules are of the same substance. Its existence may be accounted for, by supposing that the denuding currents which carried away the upper part of the tuff, cut out a sharp hollow here, which was afterwards filled up by the debris of the basalt falling from the steep flank of the cone immediately above, and cemented by the detritus of the same rock and the traptuff, washed in while the basalt was perhaps still warm.

The part of the hill extending right eastward from the apex to the little eminence of Dunsapy, seems to me to present considerable difficulties. The following ideal section does not satisfy myself, but is offered as the best explanation I can supply.

Fig. 10.



Section east and west through the apex, in the direction A E in the map. The eye is supposed to be on a level with B.

A, The apex.

B, Position of the black porphyritic basalt of the south-east limb. It is not in the line of section, but nearer the spectator, and therefore its outline merely is marked by a faint line. (See *f*, Fig. 4.)

C, The north limb of the hill, marked by dotted lines. It is beyond the line of section.

D, Dunsapy, an eminence with a marsh on its west side *s*, above which it rises probably 120 feet. The lowest bed visible is a dark blue basalt, evidently a prolongation of the highest of the blue basalts of the north limb, (*g* in Fig. 1.) This is covered by a pale greenish-grey trap, and this by a thick mass of reddish-grey trap porphyry. At the back of the hill there are indications of an amygdaloid covering the porphyry. Dunsapy is, in short, merely a detached portion of the ~~south~~ limb. north

E, A long round-backed ridge, extending like a tail eastward from the apex: it consists of two long-shaped humps or swells.

a, b, c, The overlying traptuff, (see Fig. 4.) A black line at *a*, marks the situation of the vein, shown in Figs. 8 and 9.

d, e, Loch Crag and Well Crag. From *e* to *c*, a small portion of the inclined traptuff of St Anthony's valley is seen.

The horizontal extent of the basalt, so far as visible along the line of section, is from 500 to 600 feet; (its breadth is probably 400.) Its form on the horizontal plane is shown in Fig. 7.

At *b*, next the basalt, we find the red traptuff; about 200 feet lower, we find, on the edge of the steep northern declivity, a bluish-grey traptuff marked 1. It resembles a porphyry, and perhaps may be considered as a metamorphic rock—a tuff changed by trap, which covers it, into a pseudo-porphyry: it forms a ridge partially covered with turf. About 50 yards eastward there is another ridge visible on the northern declivity, parallel to the first: this rock 2, is similar in colour to the last. It is a bluish-grey porphyritic greenstone. Eastward of this we find no rock *in situ*, but fragments are seen occasionally penetrating the soil; and where these are numerous at one spot, and the form of the surface gives reason to suppose that solid rock exists immediately under the turf, they afford a species of presumptive evidence, which is not altogether to be rejected in the absence of better. On such grounds, after a careful examination of the surface down to the marsh *s*, I infer that a bed, most probably a thin one, of very cellular amygdaloid, 3, covers the brownish-grey rock No. 2. The beds 1 and 2 are of considerable thickness, probably 100 feet or more. The two ridges in which they crop out, join so correctly at the foot with two ridges of the north limb C, that a hasty view would lead instantly to the conclusion, that the rocks on the one side of the hollow were merely the prolongation of those on the other. They are, however, perfectly distinct. The bed 2 has a considerable resemblance to 2′, the grey porphyry above the blue basalts of the north limb; and this resemblance becomes more obvious, when we take the upper beds of Dunsapy, D, as a middle term; but 1′ is not the counterpart of 1. Dunsapy is evidently a detached portion of the north limb, from which it is separated by a marshy hollow 200 feet wide; yet the rocks do not exactly correspond. There is also a difference between those of Dunsapy and the beds on the declivity E; but this difference is such, that the grey rock of Dunsapy is as near in character to 2, as to 2′, of which it is unquestionably a part. Again, there is an amygdaloid 3′ on the upper part of C, and there are traces of a similar rock, 3, on the back part of E. The supposition, however, that the rocks 2, 3, and 2′, 3′, are parts of one deposit, seems scarcely admissible. If they are, the beds 2, 3, must have sunk down through a space of 500 feet, or the beds 2′, 3′, must have been raised as much.

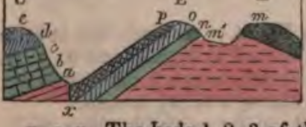


Fig. 11, Is an oblique section at right angles to the last, in the direction of the line 2′ *d*, and is intended to illustrate the fault or dislocation which seems to exist here. The letters B, E, C, represent the same objects in both Figs.

n, o, p, The beds 1, 2, 3 of the last Figure, on the ridge E, east from the apex.

c, d, e, The corresponding beds on the north limb C: *o* resembles *d*, and *p* resembles *e*; but *n* is different from *c*, and the basalts *b*, *a*, are entirely wanting under *n*.

a, *b*, The beds of basalt marked *e*, *f*, *g*, in Fig. 1, with the trap-tuff of St Anthony's valley below them.

The line of division is at *x*, at the point where the footpath leads out from the head of St Anthony's valley, and turns eastward. It is reasonable to infer that a fissure exists here, and indicates a *fault* or dislocation of considerable depth. It is marked *u* in Fig. 7.

The highest bed of basalt, *b*, of the north limb, has a certain resemblance to the black basalt of the south-east limb B, and this resemblance becomes more striking, when we take the bed of dark basalt in the lower part of Dunsapy as a middle term, which is plainly a continuation of *b*, and is nearly identical in character with *m*. For various reasons, however, it seems improbable that the rock *m* ever was connected with the other two. The hollow between *m* and *n* is about 50 yards wide, and there is a small grassy knoll at *m′*, eight or ten feet high and forty long, on the side towards E, which is so thickly strewed with masses of the black basalt, as to render it extremely probable that the rock exists below *in situ*.

There is something anomalous, too, in the relations of the north limb to the hillock of Dunsapy, considered as parts of the same mass accidentally divided. The cellular amygdaloid, for instance, appears on the side of the north limb, (under 3′, Fig. 10,) about 40 or 50 feet above the marsh; yet we seek in vain for this rock, where we ought to find it, in Dunsapy. We discover it, indeed, at the side of the ditch which drains the marsh. But if this be a part of Dunsapy, and if the beds of the hillock have the same dip with those of the south limb, we ought to find the amygdaloid somewhere on the precipice at the north-west angle, 40 or 50 feet perhaps above where it is seen at the ditch. It does not appear there, however; nor can it be sought lower; for the dark basalt, which underlies all the corresponding beds of the north limb, is found along the front of Dunsapy, 10 or 15 feet above the marsh. I suspect, therefore, that the dislocation, of which there are marks at *x*, Fig. 11, extends eastward through the hollow between Dunsapy and the north limb; and that another dislocation and fissure, transverse to the former, and existing in front of Dunsapy, at *y*, Fig. 10, accounts for its anomalous relations to the beds 1, 2, 3.

THEORY OF THE FORMATION OF THE HILL.

I shall now offer some remarks as to the mode in which the various rocks composing the hill may have been deposited in their present situations. In making this attempt, I must bespeak the reader's indulgence. Till we are better acquainted with the condition of the globe at the time to which the origin of the hill must be referred, and till the science of geology is farther advanced, our knowledge of the agents employed in the formation of mountains, and of the mode in which they operated, must be very imperfect. Fully sensible of the difficulty of the subject, the following speculations are offered merely as conjectures. They have at least the merit of being original; for if any theory of the formation of the hill is in existence, I have no knowledge of it.*

It is now generally admitted that the trap rocks have been produced by igneous fusion; and that granite, porphyry, basalt, and lava, are the same substance, assuming different forms according to the circumstances under which it was generated and thrown out. When the fused matter is forced up under a great pressure, (of water or incumbent rocks for instance,) it forms granite; under a smaller pressure, it forms trap; and when thrown out in the open air, it forms lava. Such is the opinion now generally entertained.

The rocks of Arthur's Seat seem to me to belong to three different eras, each embracing a considerable period, and implying a change in the conditions under which the rocks were formed. To the *first*, I refer all the beds from *a* to *c*, in Fig. 1; that is, St Leonard's Crag and Salisbury Crag, with the sedimentary rocks underlying and covering them. To the *second* may be referred all the rocks from *c* to *k*, (Fig. 1,) both inclusive. To the *third* era may be referred the basalt of the summit, the mass of overlying traptuff *d, p*, (Fig. 4,) which surrounds it, and the black porphyry *f*, resting upon the tuff.

Not to encumber ourselves with unnecessary explanations, we shall assume that the sedimentary rocks on which the hill stands, including all those below *c*, (Fig. 1,) already existed.

I. Let us then suppose that a portion of matter, in a state of igneous fusion at a depth below the surface, was injected among the sedimentary beds, and formed the greenstone of St Leonard's Crag, *a*, (Fig. 1.) A second portion, injected in the same way in a state of fluidity, would form the greenstone of Salisbury Crag, *b*. That the two igneous rocks were thrown out at different periods, is rendered probable by their different mineralogical character; but, from the nature of the case, it will be obvious that the higher might either be older or newer than the lower.

That the rock of Salisbury Crag was thrown out in a state of igneous fusion, and at a very high temperature, is shown by the great change which it has produced on the sandstone and shale, and undergone itself where it comes into contact with them. The sandstone changes its white colour to brown, and becomes harder, while the shale (or slate clay) is also hardened; the greenstone loses its blue tint and crystalline appearance, becomes earthy, and assumes a reddish or brown colour. If these changes were only visible at the line of contact between the two rocks at the bottom of the crag, we might suppose that the hot greenstone was laid down upon the uppermost bed of sandstone, and covered by other sedimentary rocks at an after period; but on examining the sandstone and shale which are above the crag, and rest upon it, the very same changes will be seen at the line of junction as below. It may therefore be concluded, that the greenstone was injected in a state of fusion between the sedimentary rocks, probably long after they were deposited; and this, it is to be understood, took place at the bottom of the sea. In Dr M'Culloch's opinion, the trap rocks have generally been injected among the sedimentary strata; sometimes however, but more rarely, deposited above them. There are two, or perhaps several modes, in which this injection of an igneous stratum might be effected.

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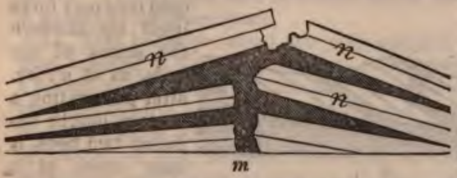
* It must be kept in mind, that the outline of the theory here proposed, as well as much of the description of the hill, was published by me in the *Scotsman* in January 1834.

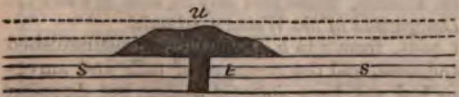
FIG. 12.



In this Figure, we may conceive *m* to be a vertical rent in the strata, through which the fluid greenstone (represented black) ascends. In forcing its way upwards, it may lift the upper strata away from the lower; and from its fluidity, it would naturally fill the vacant spaces, and thus form wedge-shaped beds, as shown in the Figure between the sedimentary strata *n*.

The rent *m*, through which the fused matter ascends, is called a vein; and there are many such in the vicinity of this city. A very large one passes through Drummond Place, crosses Broughton Street (where it is now open,) and proceeds by Quarry Holes to Lochend, about a quarter of a mile beyond which it is now quarried for paving-stone. It is about 60 feet wide, generally vertical, and is composed of a greenstone which is crystalline in the middle, but assumes a grey colour and earthy aspect at the line of junction with the sedimentary rocks, and for two feet within it. I have no doubt that the whinstone rock at Lochend, is a lateral expansion or extravasation of the matter of the vein; and the section, if exposed, would probably have the following appearance.

FIG. 13.

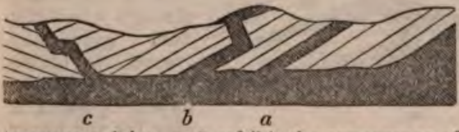


s, s, The strata composed of sandstone and shale.

- *t*, The greenstone dike, with the expanded mass of greenstone above, which forms Lochend rock.
- *u*, The upper beds of the stratified rocks, burst and shattered we may suppose by the intrusion of the trap, and afterwards swept away by the sea. The celebrated Cleveland dike, in the north of England, affords an example, at Bolam quarry, of the trap of a vein overflowing, and spreading itself out into a horizontal mass, in the manner here described. It is figured in Plate 14 of Delabeche's *Sections and Views*.

In other cases we may suppose the strata to be ruptured, and thrown into an inclined position, by motions in the igneous mass below, and to be resting on it with their ends, as in the Figure below.

FIG. 14.



In this case, the liquid trap may force itself up through the seams of the beds, as at *a*; or, after penetrating a certain length between two beds, it may cross at a transverse joint, and exhibit the appearance of *b*; or it may burst through the strata crossways, dislocating and deranging them as at *c*. In any of these cases, it is conceivable that the thicker edge of the bed may be either at the upper or lower end, according to circumstances, and the bed may still have a wedgelike shape in its section. Taken lengthways along the surface of the ground, it will be easily understood, that the separation of the beds will only extend a certain way; that the trap which fills the space will consequently thin off at each end, and appear like a section of a lens. The beds of trap in Fig. 12, will also present this appearance at the surface. In fact, trap beds have very often the form of lenses; and, compared with the beds of sedimentary rocks, are of limited extent. Portions of trap thrown up in this way, may be considered either as *beds* or *veins*.

Sometimes a trap vein subdivides into two, three, or more branches: sometimes it is bent at right angles; sometimes the trap heaves up the overlying strata into a dome-shape, without bursting them; and thus changes the position of the strata, without presenting itself at the surface. Examples may be seen in Plate 17, of Dr M'Culloch's *Description of the Western Islands*.

The next series of beds, from *c* to *k*, (Fig. 1,) are distinguished by the absence of sandstone, and the presence of tuffs and amygdaloids. These traps had not been *injected among*, but *deposited above*, the beds previously existing. The proof is, that they contain stratified traptuff; that is, trap reduced to small fragments or powder, and arranged in laminæ and strata, like slaty sandstone. This disposition of the materials can be explained only by assuming that trap, in a finely divided state, was spread out in layers, under circumstances which left it free to move in any direction; that is, either in the open air or in water. Under air, they would have been collected in irregular beds or heaps; and, in point of fact, no other agent but water could have given them the finely laminated structure which some of them exhibit. We have another proof of the absence of superincumbent rocks, in the amygdaloidal or cellular structure; for this is exactly similar to what is found in the *upper part* of currents of lava, where the smaller pressure allows the imprisoned gases to expand in bubbles, and form numerous cavities. Water, to which no rock is impervious, afterwards carries in lime, silica, carbonate of iron, and other substances, which it holds in solution, and filling up these cavities, converts the rock into an amygdaloid. The inferior part of a deep bed of lava, on the other hand, is generally quite compact.

II. This being premised, we may suppose that a mass of fused trap, existing at some depth below, and pressing upward, produced a fissure in the sandstones forming the basis of the hill, as the lava produces fissures in the sides of Etna and Vesuvius. Through this fissure the fused matter would ascend. If highly liquid, and pressed by a depth of some thousand feet of the incumbent ocean, it would spread out into a sheet or stratum of great breadth, and comparatively thin: if viscid, it would form a mass of less breadth and greater thickness round the orifice. We are at liberty to suppose, that *the sandstones were then in a horizontal position;* for the eastward dip which they now exhibit is not peculiar to the hill, but common to the adjacent country; and the original position of the sandstone and slate clay must have been nearly level. We may suppose, then, that the first liquid trap which rose through the fissure, spread out, and formed the green porphyry *c*, which lies next the sandstone in Bog Crag. A second eruption produced the porphyritic greenstone which covers it; and other successive eruptions might form the compact greenstones and amygdaloid, *d*. The aggregate thickness of these rocks is perhaps 150 feet; and while they were in the progress of formation, some traptuff must have been deposited; for we find a small portion of stratified tuff between the green porphyry *c*, and the porphyritic greenstone of Bog Crag, near the base of the south knoll.

III. We may next suppose that, for a certain period, no more liquid trap was ejected; but the same substance, broken into minute portions, probably by gaseous explosions, was cast up, or forced over the sides of the fissure. Matters of an analogous kind, namely, ashes, sand, scoriæ, and fragments, are thrown out by modern volcanoes, and constitute four-fifths, at least, of the mass of

Etna and Vesuvius. But jets of the liquid lava, when discharged into the air, often break, like water, into drops, which take a rounded form in falling, and get a slaggy surface from rapid cooling; while the same matter, projected in deep water, though it might subdivide, would not undergo a similar change. Hence the tuff of subaërial volcanoes, like Etna, will differ much from that of subaqueous ones, such as produced our traps. But a great part of the tuff of Arthur's Seat seems to consist of fragments of pre-existing rocks, including a few of the sandstones on which it rests, and in this respect, too, the analogy with modern volcanoes holds; for fragments of the subjacent rocks and of the older lavas generally form part of their ejections. It seems probable, therefore, that previous to the formation of the tuff *t*, (Fig. 1,) the fissure, probably narrow, from which the beds *c*, *d*, were thrown out, was enlarged to a wide cavity, by blowing up part of these beds, which formed its walls, and the ruins of which, no doubt, compose a part of the tuff. Indeed, tuffaceous matter, in modern volcanoes, is seldom thrown out from a fissure, but generally from a wide orifice. There is a breach at the head of Well Crag, (*b*, Figs. 6 and 7,) and the appearances there tend strongly to show that it does not pass under the tuff. Bog Crag, *a*, is evidently interrupted; for the vein *h*, and enveloping tuff, occupy the place where it should be found, if prolonged. It is *possible*, then, (indulging a wide license of conjecture,) that the breach in these beds marks the northern edge of the cavity or crater from the centre of which the tuff was vomited forth. If thrown up under the pressure of water, the fragments would not ascend far; and if we assume that they fell repeatedly back into the crater, and were re-discharged, they would undergo a species of trituration by their action on each other, and on the walls of the orifice, which would account for their comminuted state. Some geologists think that volcanic sand is chiefly derived from solid rocky substances, which have been reduced to powder by mutual attrition.* By motions of the water, or by the intumescence of the fused matter below, much would be borne over the edge of the crater, and rest on the sloping sides of the exterior. Volcanic tuffs are sometimes stratified, sometimes not; and in Arthur's Seat we find them in both conditions.†

IV. After the deposition of fragmentary matter ceased, a coulée of highly liquid trap had been thrown out, probably from a fissure in the tuff, (like the vein *h*, *k*, Fig. 9,) and formed the columnar basalt *e*, (Fig. 1,) which rests on the traptuff. This basalt is a fine granular mixture of black augite and white felspar, very uniform in composition, and precisely similar to the blue basalt of the apex. Its thickness is extremely variable, ranging probably from ten to forty feet.

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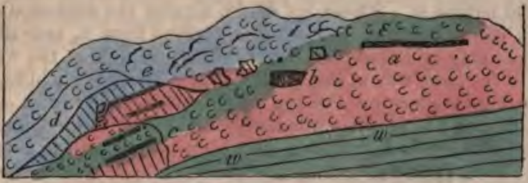
* LEONHARD *Grundzuge der Geologie und Geognosie*, 1831, p. 143. See also BURAT, *Traite de Geognosie*, Tom. iii. p. 229.

† Whether any substance analogous to volcanic ashes (which rise in clouds from Vesuvius and Etna, and float to immense distances in the atmosphere) existed here, and served as a cement to the finer fragments, is a point I am unable to determine.

Its position, which is very irregular, will be understood from the following rough sketch of the east side of St Anthony's valley. The acclivity is so steep, that it may pass for a vertical section.

FIG. 15.



w, w, The upper surface of Well Crag.

a, The basalt near the head of the valley, where it is 10 or 12 feet thick. To avoid complication, the other rocks which lie above it here are left out.

b, The basalt in a jutting crag, where it is about 50 feet thick, descends 60 feet lower than *a,* and projects 100 feet forward.

c, The basalt under St Anthony's Chapel, where it descends probably 100 feet below *b,* and also projects much farther forward. There are two beds here.

d, The vertical crag, 60 feet high, behind the chapel.

The surface of the declivity is covered with herbage, through which the amygdaloid and tuff penetrate at a few places.

The unequal heights at which we find the basalt at the localities *a, b, c,* is evidently the result of dislocations; and the cause of these dislocations is easily seen. The traptuff on which the basalt rests, is a rock of small tenacity. The erosive action of water which scooped out the valley, would cut away this fragile substance from below the firmer basalt, masses of which, thus left unsupported, slid down the declivity obliquely, and assumed a position at once lower and farther westward than the undisturbed portions of the same rock. The proof of such motion is most conclusive in the case formerly mentioned (see Fig. 2, page 7) at St Anthony's chapel. We have there the hillock jutting forward beyond the natural slope of the surface; we have the vertical crag above, laid bare by the disruption; and, to complete the evidence, we have the back or eastern part of the basalt embedded in the face of the tuffaceous amygdaloid of the crag, while the severed western part is lying under the chapel, 50 or 60 feet lower. It forms two beds, here divided by 8 or 10 feet of the rock of the crag, and two beds can be traced under the chapel too, though the covering of soil and the shifted and deranged appearance of the columns, throw an obscurity over the position of the upper. The two embedded portions of basalt will be seen under *e*, in the above figure, and the dislocated portions at *c*. The former will be seen between *k* and *i*, in Fig 2, and the latter at *b* and *c*.

Marks of derangement exist on the south side of *b*, where the traptuff is seen to be cut off abruptly by the basalt; and traces of the basalt itself are found some yards above the head of the jutting crag, and behind it. These, no doubt, formed the continuation of the rock before the mass in front was severed from it, and slipped down. It may be added, that the stratified traptuff at the well, is cut off in the same way at the south side of St Anthony's hillock, *c*.

From appearances on the top of St Anthony's crag at *e*, and over the space a hundred yards backward, I have little doubt that the crag itself (*a*, in Fig. 2) has also been moved, and is now in a lower position than it originally occupied. If the crag with the projecting mass below had been smoothed by diluvial action after the dislocation, and the embedded basalts under *e* were now found protruding through the soil, with the other beds (*b* and *c*, Fig. 2) beneath them, we would have an appearance of four beds here, while there are in reality no more than two. This remark affords a clue to the confused aspect, the occasional apparent absence, and the occasional apparent multiplicity, of the beds of basalt, eastward and southward from the chapel.

The unequal thickness of the basalt is what we would expect. If it issued forth in a highly liquid state, as its crystalline texture indicates, the coulée would accommodate itself like lava to the irregularities of the surface, filling up hollows, and flowing round, or thinly covering, small elevations in the traptuff. Hence its section along a given line may not be perfectly continuous; it may appear to thin off at some points; and it may seem to be entirely interrupted at others, because the connecting portions of the coulée have been carried away. There is little doubt that a breadth of two or three hundred feet of the traptuff has been removed in St Anthony's valley, and the basalt resting on it would share its fate.

The reader may complain of so many details, on a subject where the foundations are so uncertain. But by fully explaining the supposed process of formation in one instance, the necessity of repetition is avoided; for the history of one of the igneous beds may be considered as the history of the whole.

The amygdaloid found above the columnar basalt, is apparently the same rock in an altered form. The upper part of the basalt assumes a grey colour; the columns subdivide into small concretions; which, at a short distance above the basalt, present cells filled with spar. By degrees the cells diminish, the base takes a redder tint, and passes into the chocolate-coloured basalt. At some places, however, the distinction between the rocks is more sharply defined; and they are perhaps the produce of successive eruptions of the same matter, under circumstances somewhat different, such as a greater or smaller pressure, or a more or less abundant impregnation of gaseous substances.

The chocolate-coloured basalt *f*, passes by a similar gradation into the dark blue basalt *g*, in large columns, which covers it. At some places, too, a grey amygdaloid can be discovered between these beds, and it probably exists along their whole extent. This dark blue basalt passes again into a grey rock, which is perhaps amygdaloidal at some parts; the grey rock in its turn passes into a reddish-brown porphyritic trap *h*, above which are the amygdaloids *i*, *k*. All these may be supposed to be the produce of successive eruptions, perhaps from the same vent.

Amidst the great irregularity which prevails at the middle and north end of the hill, the three beds of basalt can generally be traced, preserving their relative positions, and serving as landmarks. We find a blue bed lowest, a bed of chocolate-red colour in the middle, and another blue bed above it.

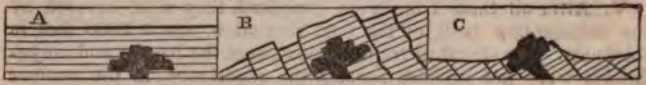
V. After all these traps were deposited, they were covered by the sedimentary beds of the coal formation, about 3000 feet in thickness. The stratified traptuff shows that the basalts and amygdaloids were not injected among the sandstones, in the manner shown in Figs. 12 or 14. They must have been laid down upon them, and under a volume of water holding the substances in solution which fill the amygdaloidal cavities. The same water had afterwards deposited above them the immense series of beds of sandstone, slate clay, bituminous shale, clay ironstone, and limestone, the truncated edges of which are seen on the beach from Fisherrow to Portobello, and which extend farther in both directions. All the beds from *a* to *k*, in Fig. 1, must have been buried under this great mass of strata.

VI. It is assumed that all the trap beds now described were in a nearly horizontal position. This conclusion rests mainly on the stratified traptuff of St Anthony's valley, which dips distinctly to the east, and at an angle which can scarcely be under 22°. This could not be its original position. The basalts too, it may be inferred, if ejected in a highly liquid state upon an inclined surface, instead of spreading out in beds of nearly uniform thickness, would have collected in masses at the foot of the declivity. Hitherto, then, we suppose all the beds from *a* to *k*, (Fig. 1,) to have been nearly horizontal; but at this epoch they were raised into the inclined position in which we now find them. There were probably two upheaving movements:—one a great and general movement, affecting all the beds of the hill, along with the strata, from the Castle to the centre of the Musselburgh coal-basin, and operating nearly at right angles to the meridian, so as to raise the west and depress the east side of the beds. In the hill, its agency is represented by the north side of Salisbury Crags; the other, a local and limited movement, directed to the north-east or north-north-east. This affected the south side of the crags, Samson's Ribs, with the eastern part of St Leonard's bed, and, to a small extent, the mass of Arthur's Seat.

In this upheaving the strata would be, as it were, partially set on their edges, and being much fractured, and exposed to the fury of tides and oceanic currents, the upper part would be swept away. The traps of Arthur's Seat having a superior degree of hardness and tenacity, would resist this action more than the adjoining sedimentary rocks; and when the process of waste and destruction had reached its ultimate term, the hill would be found projecting in bold relief above the softer strata of the coal field which once encompassed and covered it.

The three conditions of the rocks, last described, are represented in the diagram below.

FIG. 16.



A, The traps of Arthur's Seat buried under the strata of the coal field, in their original position.

B, The strata upheaved along with the traps: the vertical lines denote supposed fractures or *faults*, produced by the upheaving motion.

C, The strata with their upper part swept away by oceanic currents, and the traps of the hill standing out in high relief.

VII. When this denudation was well advanced, the volcano in the hill, after a long period of repose, resumed its activity, and an eruption of fragmentary matter ensued, which produced the great bed of overlying red traptuff, marked 6, 17, Fig. 3, *d p*, Fig. 4, and *e f*, Fig. 5. It is from 300 to 400 feet thick, and as it rests distinctly on the upturned edges of the sandstones and traps, must have been thrown out after they were upheaved and truncated. Its non-existence in the hollow between the Crags and Arthur's Seat, may be accounted for by supposing that this hollow was then filled with sandstone, above which the tuff was deposited, and that both were afterwards swept away.

A pause then took place in the discharge of traptuff, and an eruption of highly liquid matter produced the crystalline black basalt, marked *f*, Fig. 4, and *m*, Fig. 5, which rests on the tuff. After this, traptuff was again thrown out, and probably enveloped the last-named basalt, which, however, is now uncovered, the upper part of the tuff being swept away. That an ejection of tuff took place after the formation of the black basalt, is shown by a large fragment of this rock inclosed in the outer portion of the tuff on the south side of the hill. (See Fig. 5, page 12.)

The black basalt was probably hemmed in and confined by the sedimentary strata enveloping the hill, which were then only partially removed. It might thus be heaped up on the south-east side, and portions of it might penetrate downward between the older beds and the envelope of sandstone; and we may thus account for the fact of a substance, which must have been highly liquid, being found adhering to a steep declivity. The elevation of the column of the apex will explain the inclined position of the black basalt in part, but not entirely.

It may seem a violent conclusion, that the volcano remained quiescent during the vast period (half a million of years probably) in which the coal strata were deposited; and when it resumed a state of activity after so long an interval, threw out matter of the same description as before. There is nothing incompatible, however, with the observed laws of geological phenomena in this conclusion; and we have, so far as I can see, only one means of escaping from it, namely, by assuming that the beds of the hill were raised into their inclined position by a local movement, distinct from the general upheaving which placed the sedimentary strata lying eastward in a similar position, and before these strata were in existence. This assumption too, if examined, would be found to involve as great difficulties as the other.

VIII. I am inclined to consider the basalt of the apex as the newest rock of the hill; and this idea rests on the supposition that the point which it occupies marks the site of the funnel and crater of the submarine volcano, whose eruptions gave birth to most of the rocks: it follows, that when this funnel was closed by a huge column of basalt, it put an end to the ejection of solid matter. There are circumstances, however, that favour a different conclusion, to which I shall advert. The blue basalt of the apex is identical in composition with the lowest bed of the north limb *e*, (Fig. 1,) has the same external form, and the columns have the same inclination to the north-east. The blue basalt of the apex is covered by an ironshot chocolate-red basalt *f*, in small irregular concretions, and with bright specks of red; and the blue basalt *e*, of the north limb, is in like manner covered by a chocolate-coloured bed, of the same form, and with specks of red. In the apex, however, the intervening grey amygdaloid is wanting. On the side of the apex next the north limb, there is a breach in the envelope of traptuff, (from *p* to *q*, Fig. 7,) as if to afford the means of communication between the two. These facts suggest the idea, that the basalts of the north limb alluded to, and those of the apex, may be contemporaneous; and may once have been continuous, and portions of the same coulée. On the other hand, the absence of the amygdaloid in the apex, the incomparably greater depth in it of the blue basalt, and the non-appearance of a second blue basalt above the red, as in the north limb, are facts rather adverse to this supposition. The former idea, however, is not incompatible with my hypothesis. Assuming that the apex was once the seat of a crater, it only follows, if its basalts are parts of the same coulée with the beds *e* and *f* of the north limb, that the beds above these, *g*, *h*, *i*, *k*, with the black porphyry of the south limb, being ejected after the orifice was choked up, must have been the produce of eruptions from a different vent. Where that vent was situated, is a question not easily answered.

REASONS FOR CONSIDERING THE APEX AS THE SITE OF AN ANCIENT CRATER.

I. It will be observed, from inspection of the map, that the apex stands, as it were, in the centre of the traps of the hill, and in apparent connexion with all the principal beds, except those of the north limb, with which also it may be presumed to have been in connexion before the western part of these beds was carried off by diluvial action. Thus it rests upon, or rises through, Bog Crag and Well Crag: the greenstone crag *m*, (Fig. 6,) reaches within fifty yards of it: the red porphyry *n*, is equally near it: the black porphyry D, is within 100 yards of it; and all the beds of the north limb are so situated, that if the traptuff which has been removed from St Anthony's valley by denudation, were replaced, currents of fluid matter, issuing from the apex, would diffuse themselves over the space which those beds occupy. Even Salisbury Crag almost touches its foot with one extremity; and the same remark applies to Samson's Ribs, of which St Leonard's Crag is a continuation. It is to be observed, too, that the apex rises over all those rocks in elevation, as the crater of a volcano overtops the streams of lava which flow from it. Those lowest in position, namely, St Leonard's and Salisbury Crags, instead of being poured out from a vent, may have been injected between the sandstone strata from an opening in the deep-seated rocks below the apex, or communicating with it; and this either before or after the superior beds were formed.

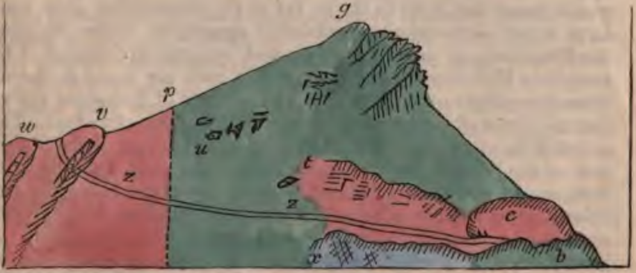
II. The position of the basalt of the apex among the other traps of the hill, is unconformable and anomalous, and gives it the character of an intruding rock. *It is not laid down upon the other rocks, but inserted among them.* This is seen in Fig. 6. It cuts off Bog Crag, *a*, and Well Crag, *b*. The first is interrupted about 150 feet from the traptuff P, and we have presumptive evidence that it does not exist concealed farther on; for the basalt in the recess *h*, occupies the place where it would in that case be found. With regard to Well Crag, there is a breach at its head about 30 feet deep, and we are sure that it does not re-appear, at least in the same line, in the space of the next 100 feet. But farther, we see the amygdaloid covering it, which elsewhere seems thin, reaching here 300 feet behind the front of the crag, while the inclination of the soil on its back increases from 20° or 25°, to 45° or 50°. This seems to indicate, that the head of the crag was not merely fractured, but *twisted back* by the protruding basalt, which is here not more than 120 feet from the amygdaloid. The position of these rocks is seen in the ground plan Fig. 7, where *b* is the head of Well Crag; *x*, the amygdaloid; *c*, the traptuff; and *d*, the basalt of the apex. The cavity A, is the head of St Anthony's valley. See also Fig. 16, below.

The greenstone *m*, (Fig. 6,) also seems to be cut off where it approaches the apex, and looks like the fragment of a huge dike, once ramifying from the apex. The two *remnants* of beds at *o*, are not altogether valueless as evidence, since their mutilated state intimates the proximity of a source of convulsive movement. It must be kept in mind, too, that the basalt of the apex is quite a different rock, in aspect and character, from *a, b, m, n*, and all the others near it. It occupies a cavity in pre-existing beds, and round it are placed half a dozen of traps, all differing from one another, and agreeing in nothing except their juxtaposition to the cavity in which the central basalt stands.

That the basalt does not rest on the traptuff, but descends within it on the west side, is clear from the description already given of the vein *h, i, k*. Nor is the evidence confined to this point. On the south shoulder at *e*, it is seen passing downwards for several yards, and joining the tuff vertically. The first view of the eastern declivity suggests the idea, that it may *rest on* the tuff there; but this is not the case, as the subjoined diagram shows.

FIG. 16.

VIEW OF THE APEX, AND ADJOINING PARTS, FROM THE NORTH.



g, The crown of the apex, as in Fig. 7.
b, Well Crag, as in Fig. 7.

c, The shoulder of traptuff, as in Figs. 6 and 7.
Remnants of the traptuff extend from *c* to *t*.

x, The amygdaloid which covers Well Crag *b*, but is seen extending here 300 feet back from it.

z, *z*, The footpath.

On the crest of the declivity *g*, *p*, the termination of the basalt, and the commencement of the tuff, can be distinctly observed at *p*, and portions of the basalt project through the soil 20 or 30 feet below this at *u*, on the northern slope. Were the rock continued eastward, either horizontally, or with such a dip as the lines of division at *g* indicate, it would be found at the small cliff *v*. This, on the contrary, is a reddish traptuff, and the small cliff *w*, which reaches considerably lower, is a grey traptuff. The basalt, therefore, is not continued to the east, but passes downward vertically under *p*, as indicated by the dotted line. From *t* to *v*, is scarcely 200 feet, and as there is abundant evidence of great denudation here, I cannot doubt that the traptuff once extended across this space, and completely surrounded the apex. It follows, that the basalt could not pass into its present situation laterally, from the east, west, south, or north, and it must consequently have come up from below. It may be said, however, that it is the older rock, that the traptuff is posterior, and was deposited around it. But this conclusion is negatived by the veins which the basalt sends into the tuff; for a vein is necessarily more recent than the rock into which it has been injected.

III. The traptuff itself furnishes strong evidence in support of the opinion, that the apex occupies the site of a crater. *First*, the great embedded masses are almost always angular, and therefore have not been rolled in water, or transported from a distance; and they are of all sizes up to four or five cubic yards, (eight or ten tons.) *Secondly*, all the fragments exceeding the size of the fist, belong apparently to the rocks of the hill. Not only are granite and gneiss never met with in it (so far as my observation goes,) but I have never seen any distinguishable specimens of the felspars of the Pentlands, or of the well-marked syenitic greenstone of Corstorphine Hill, though boulders of this rock are found in the alluvium ten miles to the eastward. Fragments of limestone are very scarce; those of sandstone more common, but not abundant. There is but little of the former under the hill; and though there is a good deal of the latter, we must remember that the rock, from its brittleness, would generally be blown to atoms by explosions sufficient to raise it from a depth of two, three, or four hundred feet. Ninety-nine in a hundred of the fragments of notable size, are of trap; and though most of them are altered, we are pretty sure that the beds in the hill could furnish them all. We have no reason to believe that any of them are positively wanting; and there are several of them which we are still able to identify. Thus we find specimens of the black porphyry, (*f*, Fig. 4;) of the cellular amygdaloids, a few; of the greenstone porphyry of Bog Crag; of the red porphyry, (*n*, Fig. 6;) and of the older traptuff itself, embedded in the newer. I have never observed recognisable fragments of the basalt of the apex. If the rock is newer than the tuff, the fact is explained. But even if it were older, the basalt being brittle, would not perhaps, if exposed to violent concussions, remain in blocks sufficiently large to prevent the change induced from penetrating to the centre, and obliterating the colour and lustre by which it can be distinguished. *Thirdly*, the traptuff is heaped up in this limited space to the depth of 300 or 400 feet, and is found nowhere else in the neighbouring country, not even on Salisbury Crags. The mass of it surrounds and envelopes the basalt, and is in contact with it on all sides. While the ascent of the basalt from below, assures us that there was a funnel here even after the traptuff was deposited, we find that traptuff placed around it, in such a manner as fragmentary matter ejected from a crater, in that situation, might be expected to arrange itself. *Fourthly*, all the ejected fragments are changed, and the change is such as might be expected if they were thrown out in a heated state, while in contact with water. A great proportion of the blue traps have assumed a red colour; some are of a deep red throughout; others, particularly large blocks, retain their original tint within. The alteration is similar to what is observed in whinstones exposed to heat when moisture is present. The blue oxide, or protoxide of iron, which is usually the colouring matter, takes an additional dose of oxygen, passes into the red oxide, and gives the same colour to the stone. As might be expected, while the blue unchanged traps of the hill are all magnetic, the red changed fragments are not, or exhibit the magnetic power in a very small degree.* The proportion of iron in basalts, however, varies greatly. The deep red tint of some of the embedded pieces, is very remarkable. The blocks of sandstone are also changed: they are hardened, have a glimmering lustre, and resemble quartz rock.

The sum of this evidence may be condensed into a few sentences. 1. We have a vast prism of basalt, stuck in vertically among rocks disposed in beds: this basalt must have issued from below at the point where it stands, and proves that an orifice once existed here. 2. Since it sends veins into the traptuff, it must be posterior to it, and must have come up in a state of fusion. 3. In juxtaposition with it, we have many beds of trap, which must have issued from below at different periods, and therefore presuppose one orifice or more through which they ascended. 4. Immediately around it we have a mass of traptuff, consisting of fragments of the lower beds of the hill, which must have been thrown up in an incoherent and heated state, near the spot where they rest, and therefore also presuppose an orifice in some such situation as that which the basalt now occupies.

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* The protoxide or blue oxide of iron is magnetic; but the red, or peroxide, is not.—TURNER's *Chemistry*, 3d Edit. p. 483.

Auvergne supplies us with facts which lend support to this hypothesis. The Puys, or volcanic hills there, often consist of cones of scoriæ, fragments, and ashes, with a crater in the middle, at the bottom of which is found a column of basalt. The Puy de Louchadiere, Mr Poulett Scrope informs us, has a crater 486 feet deep, and "at its bottom a capping of basalt conceals the orifice of the volcano, almost appearing to boil up from it, as a spring gushes from its source."[*] This cone was formed in the open atmosphere. If the sea had stood over it, it would soon have swept the upper part of the incoherent matter away; and the firm basalt which is now at the bottom of the crater, would then have projected above the rest, as the apex of Arthur's Seat rises through the envelope of traptuff.[†]

Graham's Island, which appeared in the Mediterranean in 1831, affords another illustration. It arose at a place where the previous depth of the sea exceeded 600 feet; and when visible at the surface, it consisted of a ring or circular ledge of fragmentary matter, with a pool of boiling water in the middle, from which columns of steam arose, and ashes, small stones, and red scoriæ, were thrown out. By these ejections, the circle of loose matter was enlarged to a height of nearly 200 feet above the water, and a circumference of one or two miles: the pool in the centre was from 200 to 300 feet in diameter. At length the eruption ceased; after which the fragmentary matter gradually diminished, till it entirely disappeared; and in its place was found a shoal, consisting of a black rock in the centre, 200 feet broad, and 11 feet under water, with sloping banks of scoriæ and other fragmentary matter around it.[‡] The phenomena are easily explained. The island was the product of a submarine volcano, which showered out fragments till it raised a cone 800 feet in height above the bottom of the sea. As the loose matter accumulated, the liquid basalt in the centre, protected by it, rose higher and higher, till it nearly reached the surface of the water, when it passed into the solid state by refrigeration, and the surrounding wall of scoriæ, receiving no farther additions to supply the waste occasioned by the waves, gradually disappeared.

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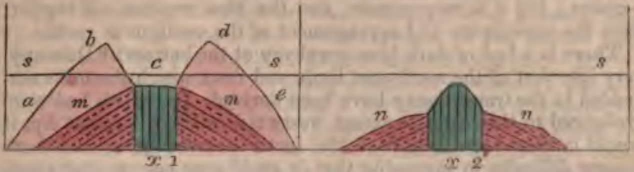
[*] SCROPE'S *Memoir on the Geology of Central France*, p. 72—81.

[†] The Puy de la Vache, the Puy Lassolas, and the Puy Charmont, have also their orifices "choked" with columns of basalt; but in each of these the side of the crater is breached, and a coulée of basalt is seen in connexion with the central mass.—See LECOQ et BOUILLET, *Vues et Coupes*, p. 110, and Plate 17.

[‡] LYELL'S *Principles of Geology*, Vol. ii. Pp. 146, 152.

FIG. 17.



In the compartment on the left, *a, b, c, d, e,* is an ideal section of the island, as it existed when the cone rose one or two hundred feet above the sea, *s s* : *b* and *d* are the ledge of the surrounding basin *c*, which then formed the crater; and *x* 1 was then an open funnel, from which the scoriæ were showered out. The shaded part represents the hill in its second stage, after the sea had swept away the upper portion of the fragmentary matter. The whole is now under the level of the sea, *s, s, s;* the sides are reduced to the size *m, m;* the column of basalt *x* 1, which was formerly the lowest part, is now the highest, and, by its superior firmness, protects the yielding materials around it. The Figure on the right represents the hill in its third stage: the agitation of the sea, for years or centuries, is supposed now to have carried away a further portion of the fragmentary matter, giving it a flatter outline, *n, n;* and the upper end of the column of lava *x* 2, has also been rounded off into the form of a cone.*

In the first stage, with the outline *a, b, c, d, e,* it exactly resembles the Puys of Auvergne; in the third, its resemblance to Arthur's Seat will immediately suggest itself.

A question of some interest yet remains: What caused the hollow on the west side of Dunsapy, now occupied by a marsh, (*s*, Fig. 10;) and what has become of those prolongations of the beds of the north limb, which must once have covered the space? To this question it is not easy to give a satisfactory answer. 1. We can scarcely suppose that the matter was removed solely by diluvial action, since other portions of the beds, not more protected, remain entire to a considerable extent. 2. The portions of the beds removed, are those nearest the seat of volcanic action, (supposing that to be the apex,) and of course most exposed to disturbance. 3. There is a *fault* exactly at the place where these beds are abruptly cut off, (*u*, Fig. 7,) showing that the prolonged portion had been broken through here, and either heaved up, or thrown down. 4. It is probable that the force which effected this, so shattered the beds, that the waters which then covered the hill were enabled to sweep the broken and loosened masses away. The cavity at this place may be conceived to have some resemblance to a crater; but it is very remote, and the idea receives no support from the appearance and arrangement of the contiguous rocks.

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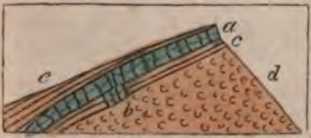
* This explanation of the changes undergone by Graham's Island, was given in the *Scotsman* of 2d November 1833, and adopted by Mr Lyell.

There is a bed of dark blue porphyry at the bottom of Dunsapy, very like that of the south-east limb, and from which the mass embedded in the traptuff may have been derived. But if this bed were prolonged to the requisite extent westward, with its present dip, it would be found at a height of 250 feet above the apex; and there is some difficulty in supposing that it could ever occupy that situation. It is not, however, impossible; and in this case the necessity for assuming an eruption of traptuff, posterior to the formation of the black porphyry, would be removed.

SALISBURY CRAG.

It has been stated already, that the greenstone of Salisbury Crag was most probably injected among the sedimentary beds which underlie and cover it. As the flanks of the greenstone are fully exposed along two-thirds of its extent, it was not unnatural to look for some indication of the opening through which the fused matter ascended; and it has been supposed that this is found on the north side.

FIG. 18.



a, The greenstone of the crag.
b, An apparent process passing downward from the greenstone, and occupying the site of the supposed funnel through which the fused trap ascended. Its breadth is probably 100 or 120 feet; its visible depth 12 or 15.
c, Strata of sandstone, shale, and clay ironstone, on which the greenstone rests, and which are interrupted by the process *b*.
d, Debris and herbage, covering all the lower part of the talus.
e, Beds of sandstone and shale, covering the eastern part of the crag on this side.

When the path was formed along the foot of the crag about twenty years ago, the rock at *b* must have been exposed to a greater depth. At present the portion visible is so inconsiderable, as to render it doubtful whether it is any thing else than an irregularity in the lower surface of the bed.

Before we leave Salisbury Crag, I must notice the vein at its western extremity. This vein is a few yards northward of the indentation called the Cat's Nick. It is about 5 feet wide, and it passes completely through the greenstone of the crag, which is here about 80 feet thick. The vein is very nearly vertical, but its sides are not perfectly straight, having a slight curvature. Externally, the greenstone of the vein scarcely differs in appearance from the rock of the crack; but when broken, instead of being granular and crystalline, it is compact and earthy, as most of the narrow trap veins which I have seen in this district are. At the junction with the sedimentary strata, it envelopes a mass of sandstone; and this sandstone, according to Mr Allan, is pervaded in all directions by minute veins of the trap, as the limestone of Glen Tilt at its junction with the granite, is traversed by laminæ of the latter rock, some of them almost as thin as paper. Such phenomena afford evidence of the fluidity of the interjected substance. The Huttonians assert that this vein had been filled by matter ejected from below, and would be found piercing the strata on which the greenstone of the Crag rests. The Wernerians controverted this; and, to settle the point, Sir James Hall had a portion of the debris cleared away, when the trap was found passing through the sandstone, as the Huttonians anticipated.

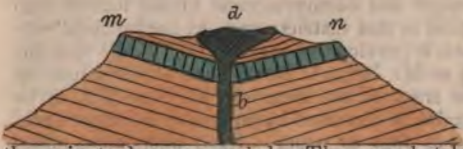
That this vein was connected in its origin with causes which have disturbed the rocks of the crags, both igneous and aqueous, seems probable from phenomena which had, so far as I know, been overlooked. It is remarkable that the dip of the crags changes exactly at the vein, in such a manner, that if we suppose the whole, formed originally in one plane inclined to the east, to have been fractured at this place, and the middle to have sunk down, or one or both of the ends to have been raised up, we shall obtain an exact idea of the appearance which the crag presents. Had this bending of the strata existed only in the greenstone, little importance would have been due to it, but it extends equally to the beds of sandstone and shale below and above. I took the dip and bearing, with considerable care, a few years ago, at various points where the sandstone below is exposed, and the following is the average :—

South side of the crags, dip N. 55° E. (nearly NE. by E.,) 1 in 2½.

North side, dip S. 80°, E. (nearly E. by S.,) 1 in 2½.

The direction of the strata of the two sides differs about 45°. The axis of depression, or the line which connects the planes, runs about N. 80° E.; and the vein is pretty correctly at its upper extremity. The rocks of the two sides, however, do not meet at a sharp angle, but are bent into a sort of curve, which extends probably 50 or 100 feet on each side of the vein. It is remarkable that the line of junction passes through a prominent mass of earthy greenstone on the back of the crag, marked 8 in the map, and *x* in Fig. 1. It was this circumstance which first led me to think that the rock in question, was a tabular expansion of the vein. This will be understood from the figure annexed, which represents a section across the crags, exactly south and north, through the middle of the terrace of greenstone 8, in the map. The vein is much thicker in the figure than it ought to be.

FIG. 19.



In this Figure, *b* is the vein which is here supposed to extend indefinitely downward; *d*, the tabular mass, marked *x* in Fig. 1, into which I suppose the vein to have expanded. The cross-hatched bed *m n*, is the greenstone of the crag, with strata of sandstone below and above, inclined to the vein on both sides. I pointed out this apparent connexion of the vein with the overlying mass 8, and with the change in the dip of the beds, to some friends, in 1827 or 1828; and they deemed it highly probable. The greenstone of *d* has a close resemblance to that of the vein, and differs much from that of the crag *m n*. It forms a raised terrace on the back of the crag, from 100 to 200 feet broad, and 500 feet long. The height at the east end is about 30 feet, which gradually diminishes till it is nearly on a level with the grassy surface at the head. This portion of it is about 50 yards from the point where the vein is seen at the edge of the precipice. The sandstone can be traced on both sides, and from its dip seems to pass below the terrace, as shown in the Figure. By opening the soil here, the existence or non-existence of the supposed connexion between the vein and the mass of trap above could be known; and considering how rarely it happens that a phenomenon of the kind, which ought to be common according to the received theory of the igneous rocks, can be distinctly ascertained, perhaps the little trouble and expense attending the experiment would be well bestowed. There is a patch of rock of a similar appearance (9 in the map) a little farther south, which is no doubt a part of the same greenstone. No trace of the vein is visible in the old quarry (10,) but the bearings of the beds lead me to think, that it should be sought farther south, pretty nearly in the direction pointed out by the line *c d* in the map.

In the preceding figure we may suppose the bed of greenstone *m n*, to be originally in one plane inclined to the east; to be fractured at *b* by thrusts from below, probably at its south end: the fused trap then ascends through the fissure, pierces the lower beds of sandstone between *a* and *b*, (Fig. 1,) lifts up the higher ones, and spreads itself laterally, so as to exhibit the appearance at *x*, Fig. 1; and perhaps the vacuum produced by the escape of the fused matter from below, caused the strata to subside in the middle, and thus made the two portions of the beds on opposite sides of the vein meet at a sharper angle. The upper beds of sandstone disturbed or shattered by the protruded trap, were afterwards swept away by the sea. We have an example of the matter of a vein, spreading out in the manner now described, at Bolam quarry in Durham, previously referred to, page 28.

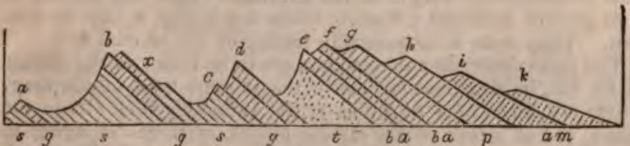
DILUVIAL PHENOMENA ON ARTHUR'S SEAT.

The traces of diluvial action on Arthur's Seat, are among the most interesting phenomena which the hill presents, and might furnish materials for a long article. I shall notice some of the most striking.

I. *All the high parts of the hill which would be exposed to the action of a current from the west, are invariably swept clean,* and where the exterior of the rock has not been altered by subsequent disintegration, the surface of the exposed parts is rounded off, smoothed, and sometimes scratched. This may be observed in the south limb, (C in the map ;) in the south-east limb (D ;) on the head of the projecting rock which forms Samson's Ribs ; and in the north limb (B,) too, though the nature of the rock is unfavourable. Though boulders, or travelled masses, abound on the hill, they are never to be found on the parts where a flood from the west could have a clear sweep, but in hollows, greater or less, behind the prominent parts. The debris, or fallen masses produced by disintegration, must be distinguished from transported blocks. Scratches may be seen on the upper surface of the greenstone of Salisbury Crag, near its south extremity.

This swept and smoothed appearance of the exposed surface of the rock, is to be observed on every low hill which I have seen in the basin of the Forth—on Braid Hill, Blackford Hill, Craiglockhart Hill, the Calton Hill, the Castle Hill, Corstorphine Hill, Cockleroy, and Earncath Hills, at Linlithgow, and others. The boulders either form a tail on the east, or are found in sheltered hollows.

FIG. 1, (*re-introduced.*)



II. *The prominence of the strata bears a proportion to their hardness and tenacity.* Why does St Leonard's rock *a,* stand out in relief beyond the strata which overlie and underlie it ? Because it is of a much harder and more tenacious substance, greenstone. In the same way, the prominent position of Salisbury Crag, *b,* is owing to the thick bed of firm greenstone which has protected the mass of less coherent strata on which it reposes. The hollows from *a* to *b*, and from *b* to *c*, were produced by the water sweeping away the looser and softer sedimentary strata, to the very edge of the protecting trap. The beds *c* and *d* are whinstone also, and therefore again prominent; while the next bed under *e* being traptuff, a much less tenacious rock, we have again a valley. The rocks from *e* to *h* are firmer than the traptuff, and hence they rise above it in a hump or swell, and the longitudinal depressions which divide them, may be pretty well explained by the varying hardness of the alternating beds of different traps. It must be understood that *all* the beds, whether sedimentary or igneous, have been partially destroyed and worn down; but the softer have suffered most, the harder least. Surge after surge had broken for a long period on the western breast of the hill, and the form of the surface has come ultimately to represent the variable power of the strata to resist the denuding agency of the water. It will be observed, also, that the apex presents the appearance of "Crag and Tail;" and the south-east limb D, owes its elevation above the adjoining surface to its capping of basalt, under the protection of which the looser traptuff is found rising up 15 or 20 feet above its general height. (See *f*, Fig. 4, page 10.)

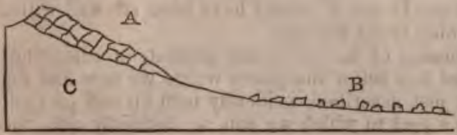
III. *Blocks of the greenstone and sandstone are strewed over the crags and hill, in a way very significant of the nature and extent of the diluvial agency.* In the map, the places of some of these boulders are marked by crosses × ×. At the north end of the Hunting Bog, on the declivity near the old quarry, (from 11 to 16 in the map,) fifty or a hundred of these may be seen, of all sizes up to 10 or 15 tons, and generally not much rounded. I have examined many of them, and they seem all, without exception, to be of the greenstone of the crag. A few are found at G, and considerably farther south. Indeed, blocks of less or greater magnitude are found all along the back of the crag, except within a short distance of the crest or edge, where the current was of course too violent to permit them to rest. The blocks at 11 had been torn off from the west or north-west margin of the greenstone bed, and hurried to their present sheltered situation, (from *b* to *c*, Fig. 4,) by the current. They seem to be generally resting on the alluvial soil.

The same description of boulders are to be found on the surface of the hill, in situations far above the present level of the crag. There is a block of 4 or 5 tons at St Anthony's Well (13 in the map;) one of 2 tons on the middle hillock of three belonging to Bog Crag; one of 4 tons on the shoulder of traptuff right north from the apex, (above *d*, Fig. 6,) 300 feet or more above the Hunting Bog. The surface below is extremly steep. There is one of 4 tons about 300 feet higher than the Powder-house, in a sort of hollow above the precipice fronting the west there, (about 5 in Fig. 3.) There are two on the south limb C, from 1 to 2 tons (between 6 and 7, Fig. 3:) there are two or three also to be found lying in the interstices between the heads of the columns among the basalt of the south-east limb D, 150 feet above the highest part of Salisbury Crag. There is one of 4 tons on a declivity at the head of St Anthony's valley; one of 7 or 8 tons at the east end of Dunsapy hill (E in the map;) and lastly, two small ones of half a ton, and a ton, at the side of the marsh behind Parson's Green. Some of these were so much rounded that I could not obtain a specimen of them; but all of them which I examined were of a greenstone, which was either the greenstone of the Salisbury Crag, or one belonging to a more distant locality. On this point there is little room for mistake; for no greenstone exists in the hill itself resembling these boulders.

What is not less interesting, blocks of sandstone from half a ton to a ton or more, are also found scattered over the higher parts of the hill, 400 feet above any spot where sandstone now exists *in situ*. One of these, of a ton, will be found on a declivity at the head of St Anthony's valley; another on the south limb; and two or three in cavities among the columns of the south-east limb D. Sandstone, from its fragility, seldom travels far; and if these masses are not remnants of the coal strata which once covered the hill, we may infer that they belong to the beds under or above Salisbury Crag, (about 1, 2, Fig. 3.) It is evident that when these blocks were transported to the situations they occupy, the hollow with steep sides which now divides the hill from the crag had not existed, at least in its present shape.

But the finest example of diluvial action which the hill affords, is to be found on the declivity lying eastward of the south-east limb D; because in this case we can distinctly ascertain the locality from which the travelled blocks came, and the direction in which they moved. The boulders in question are marked × × in the map; they are about 100 yards south of Dunsapy, and they begin about 150 yards east of the skirts of the bed of porphyritic basalt D, covering a space of 300 yards by 200. A section right eastward from the basalt presents this outline.

Fig. 20.



A, Mass of porphyritic basalt (*m* in Fig. 5,) resting on C, the traptuff.

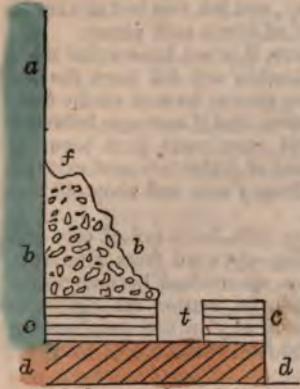
B, The boulders, or detached blocks.

The boulders are some thousands in number, of all sizes, up to cubes of 6, 8, or 10 feet, weighing 20 or 30 tons: they are generally not deprived of their angles, and they are scattered about in the wildest confusion. In some of them we find the seams of the columns well marked, like the lines in a Mosaic floor, while the mass still coheres as one solid piece. There are a very few blocks of sandstone among them, and perhaps a few of other trap rocks; but nineteen-twentieths are easily recognised as part of the basalt A; some few of them exhibiting rather a larger proportion of felspar than the columns *in situ*, as belonging probably to an upper bed, of which they are the wrecks. Now, the facts deserving of notice here are:—that there is no precipice from which they could fall; that in this situation, 300 feet above the general level of the country, they are quite beyond the reach of all transient floods and currents; that no cause, in short, now operating, could have detached them from the parent rock, and placed them in their present position; and that this could only have been effected by a powerful current from the west, which tore up the higher parts of the basalt D, and transported the fragments to the place where we now find them. We can judge of the direction of the current too; for if we start from the brow of the height above the Duddingston footpath, (34 in the map,) and proceed northward towards the marsh at the foot of Dunsapy, we shall find that the fragments cease when we arrive opposite the hollow which bounds the south-east limb D, and separates this rock from the apex and its tail. It is farther worthy of remark, that all the large blocks appear partially earthed up, the west side presenting a mimic terrace one or two feet above the east. One huge boulder of 30 or 40 tons stands just on the edge of the declivity, in such a position that it is difficult to conceive how it could have been in motion, and brought to this spot, without rushing down the steep. The most probable explanation of the fact is, that when the boulder was impelled to its present situation, the clay and sand were then many feet deeper, and formed a resisting medium, which stopped it at a point where the slightest motion in the present state of the surface would precipitate it down a declivity of 300 feet. And while the waters were receding, a part of the alluvial cover might be washed away. Numerous blocks of a rock closely resembling this, are also found in front of Dunsapy, and might lead to a suspicion that the rock at D was once continuous with the blue trap at the bottom of that small hill; in which case the masses alluded to would be fragments of the beds that once connected D and E. But, on this supposition, all the space between D and E should have been strewed with the same boulders, which is not the case.

The travelled masses of sandstone and greenstone belonging to beds some hundred feet below the places where we now find them, and the boulders just described, evidently torn up and carried off by violence from a spot to which we can so distinctly refer them, are most instructive memorials of the wondrous changes which the surface of the country here has undergone since the solid strata were deposited. In this case, it may be truly said, that rocks and stones have a voice, and speak an intelligible language to the reflecting mind.

When excavations were made in 1828, below Samson's Ribs, (at *g* in the map,) a very interesting section of the soil was exhibited, of which Fig. 21 will convey an idea.

Fig. 21.



a, b, c, The surface of the rock, which is here quite vertical: it consists of porphyritic greenstone in long columns, two feet or more in diameter.

b, b, A mass of debris, the spoils of the mural precipice, about 40 or 50 feet deep from the old footpath *f,* downwards. It is a confused assemblage of angular blocks, of all sizes, up to 20 or 30 tons weight, and all belonging to the rock above.

c, c, A bed of clay about 10 feet thick, on which the fragments reposed.

d, d, Strata of sandstone and shale, dipping to the north-east, passing under Samson's Ribs, and supporting the bed of clay.

t, The cut made for the tunnel.

The clay, *c c,* was of a yellowish colour, with patches of blue and red, and was in some degree unctuous. It contained many stones, but these generally small: nine-tenths of them were of sandstone, and angular; a few of greenstone, and rounded; but none that could be traced as belonging to distant localities; and only a very few bits, if any, of the rock above. The clay must be assigned to the newer alluvium.

The existence of this bed of clay under the fragments, may be explained with or without the supposition of a transient deluge, like Noah's flood. First, it is obvious, from the nature and position of the rock, that portions of it must always have been falling down at intervals, since its front was exposed by the removal of the contiguous strata. Had the base *d d* been left bare when the fragments began to fall, we should have found them reaching down to it, instead of being separated from it by ten feet of clay. Again, if this bed of clay had been slowly deposited during a course of years, by causes now operating, we should have infallibly found angular masses of the rock intermixed with it, which is not the case. The clay, on the other hand, is not a portion of the older alluvium found in other parts of the adjacent country, and which, from the abundance of rolled blocks contained in it, may be supposed to have been deposited by some of the vast currents which broke up and carried off large portions of the rocks. We must either assume, then, that a feebler current, following these, deposited this clay, and in so short a period that the debris of the columns had not time to mingle with it, or that, after many fragments had been accumulated here, a new and powerful, but transient irruption of the waters, carried them away, and left this bed of clay in their place, upon which a new deposit of debris took place.

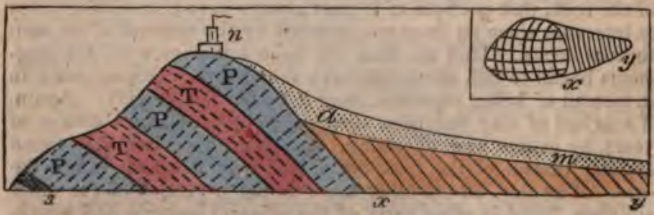
During the last fifty years, I believe, it is not known that more than two or three blocks of any noticeable size fell from the columns; and if they did fall, they were sure to be seen on the footpath below. We may therefore conceive, that if meteoric influence has not been enfeebled, many thousand years must have been required for the accumulation of the mass of fragments now existing here, which was about 50 feet deep from *f* to *c*, and about 30 feet in breadth at the base.

Arthur's Seat, like the neighbouring hills, has a tail of clay and gravel, which may be seen proceeding eastward from Dunsapy. I am not aware that its depth has been ascertained by quarries or openings in the soil; but beds of alluvial matter are visible at Duddingston Mills, (150 yards eastward of *f* in the map,) on the banks of the stream, to the depth of 60 feet, without any rock.

THE CALTON HILL.

This hill is in the north-east part of Edinburgh. Its summit is 349 feet above high water at Leith. The western part consists of porphyry and traptuff; the eastern, of numerous alternations of sandstone, wacké, bituminous shale, and clay ironstone. Its extreme breadth from north to south, is about 1300 feet; its length to Carlton Place, about 2500.

Fig. 22.



The above section of the hill, in an east and west direction, is by

Mr Webster, who studied in this city many years ago, when some parts of the hill were exposed which are now covered up. The part of the section between *x* and *y*, is no longer visible.

P, T, P, T, P, Five beds of alternating traptuff and porphyry: the highest, crowned by Nelson's Monument *n*, is porphyry; the second, traptuff; the third, porphyry; the fourth, traptuff; and the lowest, porphyry. This last envelopes a mass of sandstone and shale, *s*. I have never carefully examined these rocks, which have a considerable resemblance to each other; but Mr Webster's description is in substance as follows:—The principal rock is porphyry, with a basis of claystone, sometimes passing into felspar, sometimes into a distinct greenstone; and upon these rest alternating beds of traptuff and porphyry.

Boué describes the trap beds as follows:—1. (the lowest) A greenish trap porphyry. 2. An earthy-greenish or greyish-black dolerite, having the aspect of a breccia, and traversed by many calcareous veins. 3. A greenish doleritic porphyry. 4. A greenish or purplish brechiform trap. 5. An earthy felspathic amygdaloid, greenish or purplish-grey, with embedded crystals of greenish decomposed augite, and scales of oxidulous or titaniferous iron. Its cavities are filled with carbonate of lime. 6. A true breccia, composed of fragments of greenish wacké, and of compact or earthy felspathic rocks, agglutinated by comminuted debris of augite and titanic iron. In the text he makes the number of beds seven; and if all the varieties were distinguished, they would perhaps be still more numerous. He considers the uppermost as the only true traptuff, the others as pseudo-tuffs.* There are, I think, three true tuffs in the hill; and on the high south walk, a bed of sandstone is exposed, covering the porphyry on which the monument stands. The beds of tuff are generally much thinner than those of porphyry. Some of the former probably do not exceed 10 or 15 feet in depth, while the lowest bed of porphyry is perhaps 150 feet. In this and other respects the above section (which, so far as the rocks are concerned, is borrowed from Mr Webster) has no pretensions to accuracy.

The east end of the hill (from *x* to *y*) consists of beds of bituminous shale, wacké, sandstone, and clay ironstone. The wacké forms two-thirds of the whole. The beds of sandstone are but a few inches thick, and the bituminous shale has nodules of clay ironstone intermixed with it. Mr Webster enumerates seventeen beds, then exposed; and the thickness of twelve of these, as given by Boué, amounts to 170 feet. As a specimen of alternating beds, I subjoin a list of these, beginning at *x*, the west end.

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* Boue, Pp. 182, 476.

1. Bituminous shale.
2. Wacké.
3. Sandstone.
4. Bituminous shale and ironstone.
5. Wacké.
6. Bituminous shale.
7. Wacké.
8. Bituminous shale.
9. Wacké.
10. Bituminous shale.
11. Wacké.
12. Bituminous shale.
13. Wacké.
14. Bituminous shale.
15. Wacké.
16. Bituminous shale.
17. Sandstone.

The dip is E. N. E., and about 15°.

Wacké is a sort of earthy greenstone, so soft that it yields to the nail. This section extended along the space now occupied by Regent Terrace. Though 200 feet or more in length, it contains only two beds of sandstone, and these only a few inches thick. Now it is remarkable that, on the north side, behind the Royal Terrace, there are six or eight beds of sandstone visible, some of them six feet thick, intermixed with vast beds of dark shale. The space separating the localities presenting these different appearances, is from 300 to 600 feet broad. The direction of the beds here is N.N.W.; and whether the beds seen on the north side in part replace those on the south, or whether they belong to a portion more distant from the trap, I am unable to determine.

The Calton Hill also exemplifies beautifully the phenomena of "Crag and Tail." To the west we have every where a craggy front of trap rock, (*s* to *n*,) worn bare at all its most prominent parts, and thinly covered with turf elsewhere. On the east, (*x* to *y*,) we have portions of strata which once overtopped the trap, and spread far to the south and north, but are now cut away to a mere remnant, which has been sheltered by the firm trap from farther denudation. The small diagram in the corner of the preceding Figure, showing the form of the hill on the horizontal plane, will make this better understood. The cross-lined space is the head of trap, and the point *x y* is the tail of soft strata, which has been cut away to a small breadth. That the trap has not been cut away *laterally* to any great extent, is proved by the opening lately made at the gas-works in New Street. The sedimentary strata were found here in their usual position, quite undisturbed, within 30 or 40 yards of the south flank of the trap, where it forms a precipice 100 feet in height, and descends probably as much below the level of the strata. On the top of the hill there are but a few inches of turf, even in the least exposed situations; but on the lower eastern slope we have a covering of earth and clay, (*a*, *m*,) from six to twenty-five feet thick. The clay contains many stones, a few of 24 or 30 inches diameter, but the far greater proportion not exceeding a foot. They are generally of the trap and sandstone of the hill; but I have seen rolled fragments among them of the very peculiar sienitic greenstone of Corstorphine Hill. The clay has portions of sand mixed with it at some parts.

There is a greenstone vein, about twelve feet broad, exposed on the footpath passing down to the Royal Terrace; and it is also seen on the declivity below. It is probably a branch of the great vein which passes along the north foot of the hill to Lochend.

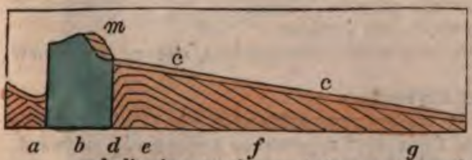
The stratified tuff which is seen opposite Bridewell, and in other parts of the hill, shows that the trap beds had been deposited on the surface of the sedimentary rocks, not injected among them. But any extended theoretical view of the formation of the hill, is rendered unnecessary by the remarks previously made on Arthur's Seat.

THE CASTLE HILL.

The hill on which the Castle stands is a mass of basaltic clinkstone, about 900 feet in length from north-west to south-east, and about 700 in breadth in the transverse direction. It is a remarkably bold picturesque rock, bounded by craggy cliffs on all sides, except at the south-east angle, where it joins the ridge on which the old town stands by a narrow neck. The mass of clinkstone is surrounded on all sides by sedimentary strata; and its relations indicate that it had been protruded from below in a solid state after the strata were deposited; that in its ascent it had pierced, fractured, and disturbed them; and that the part of it visible may be considered as the summit of a vast column, reaching probably to a considerable depth downward. The rock is of a blue colour and fine grained, and contains a few grains of pyrites. Its numerous parallel fissures, chiefly in a direction approaching to the vertical, exhibit a semblance of stratification; but the appearance is merely superficial, and due probably to the mode in which it cooled from a state of fusion.

The following section shows its relations to the rocks on the east, forming the ridge on which the old town stands:—

Fig. 23.



b, The column of basaltic clinkstone.

e f g, The strata under the High Street, extending a mile eastward, and dipping to the east (more correctly E. by N.,) at an angle of 15°.

m, A portion of the strata adhering to the trap under the half-moon battery.

A part of the strata *e f g*, are laid bare on the New Approach under the Esplanade; and the crest of a portion of them was exposed in 1833, in opening a trench for gas-pipes from the Tron Church to the Castle Hill. I examined it several times; and from ocular inspection, and questions put to the workmen, I learned, that nearly the whole consisted of red and blue slate clay. At the Esplanade also, four-fifths of what is visible are of the same soft and feebly coherent substance, with only a very few beds of sandstone intermixed; and we can thus the more easily comprehend how it would be cut away by a powerful current, till it assumed the form of a long narrow ridge, protected at the head by the column of basalt *b*.

c c, A bed of alluvium of variable thickness covering the ridge.

The mass of basaltic clinkstone, as already observed, is about 900 feet long from S.E. to N.W., and 700 feet broad in the transverse direction. The subjoined diagrams are sections, No. 24 in the direction of its length, No. 25 in that of its breadth.

Fig. 24.

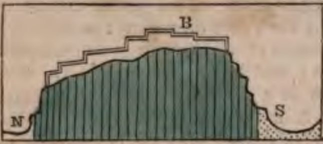
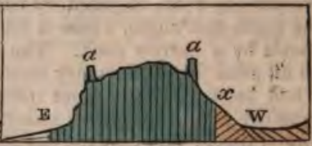


Fig. 25.



N, The north end of the trap rock, which rises in a vertical precipice about 100 feet above the surface of the gardens in the North Loch. The soil under N, consists of clay and debris.

S, The south end of the rock, which rises nearly 250 feet above the road at the king's stables, and 150 above the west approach. The soil here consists of debris. The double line along the head, is meant to show how the castle walls rise by successive steps to B.

B, The highest part of the rock is under this letter, near the chapel. It is 434 feet above the sea, and 287 feet above the surface of the gardens in the North Loch at N.

Fig. 25, is a transverse section of the Castle rock passing through the new barracks and the governor's house.

E, The east side, within the gardens.

W, The west side, also within the gardens, and near the new bridge.

a a, The walls of the castle.

The sedimentary strata are not visible at E; but their existence here may be inferred from their appearance a short way eastward.

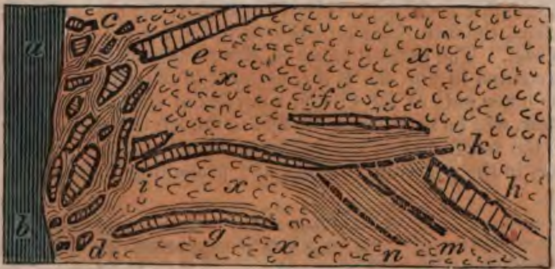
On the north-west side the strata are seen at a seat in the gardens, dipping northward and eastward, (or in towards the trap.) About 120 yards westward from this, they dip north-west at 45° or 50°. Thus, at a point near the Castle, probably 80 or 100 yards from it, the dip of the strata is reversed. This is shown at W, and above *a*, in Fig. 23. Something analogous is seen on the south-east side. Nearer the bridge, on the west side, the strata are seen in contact with the trap. They consist of sandstone, and dip north-west at a pretty high angle, presenting their edges to the trap, neither inclined from, nor towards it. The sandstone has a deep red colour, is hard, and, at the point of junction, presents the appearance of vertical laminæ, parallel to the surface of the trap, leaving us in doubt whether it is not really a mass placed on edge, and the traces of a northern dip a delusion. The trap, also, is discoloured to the distance of a foot from the junction.

The sedimentary beds at W, rise to a point *x*, about 80 feet above the cart-road passing under the bridge. They are thickly covered by the debris of the trap, except at the two points where they have been artificially laid open.

I have stated that the sandstone at W, and the trap in contact with it, are both discoloured. The inference is, that the trap was hot when it was protruded from below. It would seem also to have been *soft*, perhaps *viscid;* for Lord Greenock remarks that "within the Castle walls, fragments of sandstone are imbedded in it;" * yet it certainly was not *liquid*, at least in the exterior parts, for if so, we would have found veins proceeding from it, at the fine section under the half-moon battery, (Fig 26,) where the ruptured fragments must have presented many interstices, into which a fluid could easily have penetrated. Indeed, the groovings on the surface of the trap here, prove that it had been moved after consolidation. But the exterior parts, being in contact with the cold strata, must always have consolidated first, and hence an intruding mass of trap might be firm, but still hot, while the internal parts were liquid. The curious phenomena of metallic veins, however, lend some countenance to the idea that igneous and sedimentary rocks placed in contact, may undergo a mutual change of constitution from the influence of electricity, or some analogous agent.

FIG. 26.

SECTION UNDER THE CASTLE GATE.



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* Transactions of Royal Society, Ed., Vol. xiii. p. 41.

This very interesting section is on the new approach, under the south end of the half-moon battery.*

a, b, The basaltic clinkstone, the eastern boundary of which consists of a slightly waving vertical plane, running north and south.

c, d, A confused mass of large blocks and fragments of sandstone, intermixed with blue and red slate clay. The blocks of sandstone are of all sizes, up to 10 or 12 feet in length. The fine lines represent the laminæ of the slate clay. The space occupied by these fragments, from the trap *a b,* to *i,* is about 25 feet in breadth, and may be considered as a great fissure produced by the rending of the strata, and afterwards filled by broken materials falling in from above. The entire height up to the Castle wall, is nearly 100 feet; but that of the part shown in the Figure is only about 70 or 80 feet.

e, A portion of a bed of sandstone six feet thick. There is another in a parallel position, three or four yards above it.

f, A bed of sandstone, two feet thick.

i, k, A bed of sandstone parallel to *f,* about two feet thick at the west end, and thinning off on the east.

g, A bed of sandstone, two and a half feet thick.

h, A bed of sandstone, about six feet thick.

m, n, Very thin beds of the same.

x, x, x, x, Soil and herbage.

The fine lines represent the slate clay, and show the direction in which its laminæ extend. It will be observed that those between *n* and *h,* are transverse to those between *i k,* and *f.* Various explanations have been given of this phenomenon, which, however, I shall not stop to examine.

From *b,* to the bed *h,* the distance is about 250 feet. The section is not vertical: the surface is inclined at an angle of about 50°.

The beds *h m n,* show the position of the strata under the old town; these strata extend nearly one mile to the eastward, and all dip to east, at various angles from 12 to 20, averaging perhaps about 15°. The beds *e, i k,* and *g,* have a western dip where they approach the trap, and are nearly level farther east. This unconformable position is evidently caused by the upheaving of the clinkstone, the disturbing influence of which has extended 250 feet to the east. The general effect of this arrangement of the rocks is represented in Fig. 23, at *d e,* divested of the details. On entering the outer gate of the Castle, a portion of strata, some yards in thickness, will be seen about 100 feet to the left of the guard-house, under the south end of the half-moon battery, having the same dip as *e,* in the preceding Figure, and presenting their raised and truncated ends to the east. On the right of the guard-house, however, under the north end of the same battery, a mass of strata, (*m*, Fig. 23,) is exposed dipping to the east. These seem to consist of portions of the strata borne up with the trap, and adhering to it, without changing their position; while the other, which either incline to the trap, or are horizontal, had been shaken, bent, and shifted, by the disturbing movement, of which we have such striking evidence in the fragments filling the space between *i* and the trap rock *b*.

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* The diagram is roughly sketched from a hasty inspection of the locality. A very correct drawing of the section is given in Lord Greenock's paper, on which I could not lay my hands when it was wanted.

At *b*, close to the road, some yards of that part of the surface of the trap are exposed, which had been in contact with the sedimentary rocks. It is smoothed, and marked with grooves which are nearly vertical, suggesting the idea, that in its ascent from below, it had been abraded by the fractured ends of the sandstone strata.

Since it appears that the strata on the opposite sides of the Castle rock (neglecting the small portion in contact with it) dip in opposite directions, those on the east side eastward, and those on west side westward, the question arises, whether the intruding trap, in ascending from below, moved them into this inclined position? That it was the agent by which the change was in part effected, seems probable. If we assume that the original position of the strata was horizontal, and that the clinkstone mass, pushed up in the solid state, broke and pierced them, we would expect to find the fractured strata, if not afterwards disturbed by other causes, leaning against the trap, and dipping away from it on all sides. We might also account for the anomalous position of the portions of the beds nearest the trap, (at *a* and *d*, Fig. 23,) by supposing that the column was hot when it ascended, and having afterwards cooled, it shrunk, as all bodies do in the process of refrigeration, and, in subsiding, carried the adhering ends of the strata down with it. According to Mr Adie's very careful experiments, the linear contraction of a column of Ratho greenstone, in cooling through 1000 degrees of Fahrenheit's scale, (namely, from a red heat to that of our climate,) would be about 4½ feet for every 1000. Supposing this to be the amount of the change of temperature, and the ends of the strata to be bent downwards 20 feet, the column of trap would require to be 4400 feet, or four-fifths of a mile in length, to account for the change of position. That the trap was hot when it ascended, may be inferred from the discoloration it has communicated to the sandstone, and undergone itself, at the point of contact; and that in cooling it would contract both in length and breadth, is certain; but our knowledge of all the facts is too limited to enable us to arrive at positive conclusions. We are ignorant of the length of the trap column, and its temperature at the time of its ascent, and as for the altered position of the sandstones *e*, *i k*, and *g*, it may be the simple effect of disturbance.

The position of the strata in the southern districts is precisely the same as under the High Street. This was shown by openings in Nicolson Street, near Surgeon's Hall; in Lothian Street, at the foundation of the Catholic Chapel; behind Brown Square, at the foundation of George IV. Bridge, and elsewhere. The E.N.E. dip of the rocks, 1500 feet south from the High Street, and 2000 feet from the Castle, could not be the consequence of the upheaval of the mass of basaltic clinkstone; for if so, the inclination should have been S.E., that is, nearly at right angles to what we find it. At Keir Street, again, 1000 feet south from the Castle, the dip is slightly north, of course the reverse of what it should have been. At the deep opening 500 feet south-west from the Castle, intended for a street, (marked Grindlay Street in Kirkwood's map,) the dip is not S.W., that is, away from the trap mass, but N.W., at 10° or 12°.

It thus appears that the arrangement of the rocks all round the Castle, is not such as the simple action of the mass of trap upon horizontal strata, which it pierced and upraised, would produce; yet the appearances in the section, Fig. 26, clearly show that it did alter the position of the strata to some extent. Besides a thousand geological facts prove, that trap has been a chief, though not the sole agent, in throwing the sedimentary rocks into the infinitely varied positions in which we find them. Perhaps the most legitimate conclusion is, that the trap rocks visible, are to some extent the *cause*, but to a greater extent the *sign*, of disturbing movements, which had their origin at a depth under the surface. Trap is abundant in the district, as will appear from the following enumeration of beds and veins independent of those in Arthur Seat, the Calton Hill, and the Castle.

The great vein of greenstone, 60 feet broad, passing through Drummond Place, Broughton, and by Quarry Holes, to Lochend.

Two thin beds in Lothian Street, exposed in 1817.

A bed in Merchant Court, Cowgate, at the foundation of Geo. IV. Bridge.

A bed abound three feet thick, was found in sinking a well in Mr Berwick's brewery, Canongate. It is perhaps a continuation of St Leonard's bed, which is seen at St John's Hill, 1000 feet southwards.

A thick bed at Bell's Mills, at the bridge. Two veins at the Mineral Wells at Stockbridge, which, by their numerous fissures, serve as conduits for the mineral water. The one is about 12 feet broad, the other 6.

A bed behind Bread Street, at the cutting made for Grindlay Street.

A vein was met with by Mr Jardine in tunnelling betwixt Watson's and Heriot's hospitals for the Waterworks.

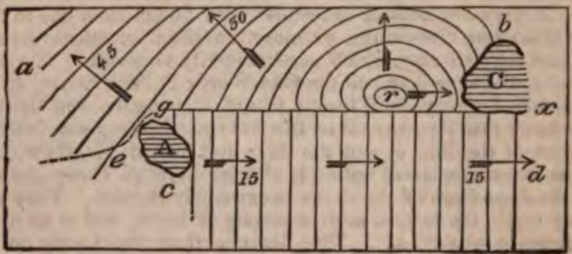
A vein was found in the east part of Canonmills in cutting a drain, and one westward of the village, in Mr Eyre's ground, (Mr Jardine.)

Considering how small a part of the surface has been exposed since geology was studied here, we may safely assume that the trap beds and veins observed, bear a very small proportion to the entire number existing. I have applied the term *beds* to those masses which lie conformably among the strata, though they may with equal propriety be considered as *veins*, since they have generally, if not universally, been *injected* among the strata, instead of being laid down upon them, as one sedimentary rock is deposited above another. In one respect, however, they differ from vertical veins cutting across the strata, such as those at the Mineral Well, and the great vein at Lochend, as the latter have probably in some cases been filled from above, or from a mass of liquid trap at one of their extremities. The matter of the great vein, for instance, has been supposed to have flowed from the trap of Corstorphine Hill, into the fissure where we now find it. The erupted traps, therefore, namely, the Castle rock, and the various beds and veins, may be considered as extravasated portions, belonging to a larger mass now, or once existing, at a certain depth below, and affording clear indications of its disturbing agency.

The strata under the High Street were exposed in 1835 from Niddry Street to the head of the West Bow, a distance of 1500 feet. A very few beds of sandstone were found, from one to four feet thick; but nine-tenths, or more, consisted of alternations of blue and red slate clay, which were generally very soft. The same sort of rocks were found at the Gas-Works in New Street, at Mr Berwick's Brewery in Wilson's Court, Canongate, and there is little doubt that they extend to the Abbey. No trap was found in any part of the line, except the three feet bed at Mr Berwick's; and, as not unconnected with this absence of trap, I may observe, that the disposition of the strata is extremely regular. They uniformly dip to the east, or more correctly E. by N., and at an angle averaging probably 15°. The distance from the Castle to the Abbey being almost precisely one mile, the true thickness of the beds will be about 1200 feet, and the number of alternations of blue slate clay, red slate clay, and sandstone, estimating them at 18 inches on an average, will be 800. Of the entire series, the sandstone probably does not constitute one-tenth. There is perhaps a little limestone and clay ironstone, though I did not observe them. It is this absence of firm rocks which had enabled the diluvial current to cut the strata away so closely on each side, and form so sharp a ridge.

I have no doubt that a deep fissure, or FAULT, *extends along the hollow of the North Loch;* for the strata under the New and the Old Town are placed in positions altogether dissimilar. Owing to a thick bed of diluvium which covers much of the site of the New Town, the rocks are rarely seen; but the strata were well exposed last year at the New Club-Room; and I am indebted to the kindness of Messrs Grainger and Miller for notices respecting those in the line of the Newhaven Railway. From these I find, that the strata under the east side of St Andrew's Square are horizontal about the middle, but decline a little to the south on the south side, and to the north on the other. Of 66 feet pierced, more than nine-tenths was slate clay. At Queen Street lane, the dip is 1 in 4 or 5 to the north. At the New Club-House in Prince's Street, the dip was north-west, at angles from 30° to 40°, and nearly the whole, in the space of 60 feet, was blue and red slate clay. At the West Church Manse, beds of slate clay were exposed 100 feet thick, dipping north-west at 45° or 50°. At Rutland Street, the strata dip north-west at 45°, but here sandstone abounds. In Melville Street, and at the west end of Maitland Street, the dip is the same. Thus, speaking generally, we may say that the strata under the New Town, from St Andrew's Square westward, dip north-west at a very high angle; while those under the Old Town, placed parallel to them at a distance of 700 or 1000 feet, dip uniformly to the east. This will be rendered more intelligible by the subjoined diagram: it is a ground-plan or horizontal section.

Fig. 27.



A, The trap rock of the Castle.
C, The trap rock of the Calton Hill.
a, *b*, The strata under the New Town.
c, *d*, Those under the Old Town, eastward from the Castle.
g, *x*, The supposed fissure or *fault*, running along the hollow separating the New and Old Town, called the North Loch.
r, The point in St Andrew's Square where the strata are horizontal, and from which they decline in all directions.

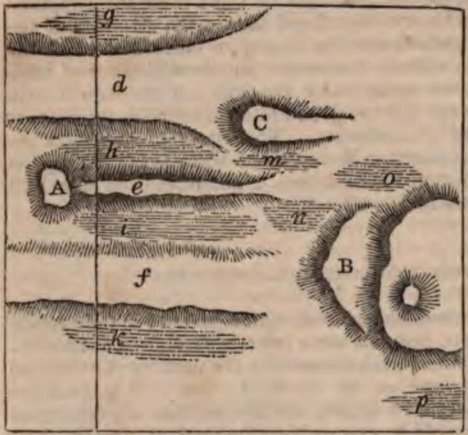
The lines mark the *direction* of the strata, or the appearance their outcrop edges present on the horizontal plane; the arrows show the point of the compass to which they dip; and the accompanying numbers, the degrees of inclination, so far as known. The eastern dip between *r* and C is merely inferred, the strata not being visible.

The strata on the west side of the Castle, perhaps as far as Portsburgh, agree with those of the New Town, in dipping to the same point; but a sudden and great change in the degree of inclination takes place between Grindlay Street and the ground at the Unitarian Chapel near *e,* which leads me to think that the supposed fissure in the North Loch takes a bend here in the direction of the dotted line *g, e.* I am aware of the numerous inflections which the strata often undergo without fractures; but the difference of position here, betwixt the rocks under the Old and the New Town, seems to me too abrupt and too great, to be accounted for without supposing a rupture of continuity. The cause of a change so complicated, however, cannot be explained, without the assumption of various upheavings and subsidences, a full discussion of which would be out of place in this Sketch.

DILUVIAL AND ALLUVIAL PHENOMENA.

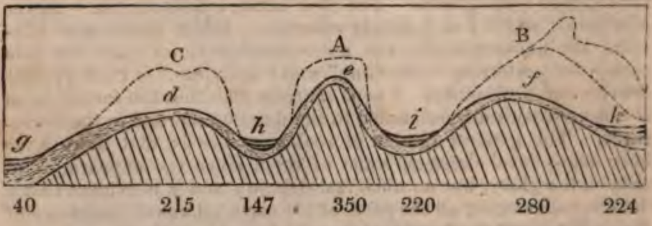
The coat of clay, sand, and gravel, which covers the solid rocks, except at a few points, presents some interesting objects of inquiry. It is, like the sedimentary rocks, generally the product of causes no longer in action, (at least on the dry land;) but as it is the latest product of these causes, its origin, and the peculiar circumstances which attended it, should be more within the reach of investigation. In this district it consists of three descriptions of matter: 1. A stiff blue or red clay, with rolled stones, the "older alluvium," which I call *diluvium;* 2. A softer clay, with rolled stones; 3. Sand, or sand mixed with gravel. The two latter constitute the "newer alluvium," which I call simply *alluvium.* Older and newer alluvium are unquestionably the more suitable terms; and my sole reason for preferring "diluvium" and "alluvium," is their greater brevity and distinctness. I need scarcely add, that the former term is not used with any reference to the deluge recorded in the Scriptures. The general opinion of geologists now is, that there have been many local deluges, some of them since the appearance of man on the globe, but no universal deluge; and it is evident that a deluge, submerging all the parts of the earth inhabited in the age of Noah, would attain the object for which that catastrophe was sent.

FIG. 28.



In this miniature map, A is the Castle; B, Salisbury Crags, with Arthur's Seat behind them; C, the Calton Hill. The city stands on *three ridges, d, e, f,* separated and bounded by the four swampy hollows, *g, h, i, k.* This will be better understood from the section below, which runs south and north along the line *g h* in the map. The letters in the map and section correspond.

FIG. 29.



The section shows the three ridges in connexion with the trap hills C, A, B, to which they apparently owe their existence. The figures under the letters *g, d, h, e,* &c., denote the various elevations of the ridges and hollows, in feet, above the level of the sea. The part marked by oblique lines represents the rocks; and the narrow belt of dotted space over this, is the alluvial matter. The horizontal distance from *g* to *h* is about 2300 yards, or 1⅓ mile. The elevations are a little exaggerated.

g, The meadow extending from Silvermills to Canonmills. There is a great depth of sand here, probably 30 or 40 feet: under this lies a bed of clay, which, northward at the Botanic Garden, attains a depth, I believe, of 80 or 100 feet.

d, The ridge on which the New Town is built.

C, The Calton Hill in outline, which stands at the eastern termination of the ridge *d*.

h, The North Loch. It was formerly a lake, and constituted the best defence of the town on the north side, in early times. The bottom is still marshy, and there is a great depth of alluvial matter in it.

e, The sharp ridge on which the Old Town stands, about 100 yards east from the Castle.

A, The trap rock of the Castle in outline, which is at the west extremity of the ridge. It rises about 280 feet above *h*, the marshy surface of the North Loch.

i, The hollow occupied by the Grassmarket, which is continued eastward by the Cowgate. It was once a marsh; for a black substance, of the nature of moss, was found at various depths from six to fifteen feet, below the level of the Cowgate, at one of the piers of George IV. Bridge, and at the foundation of the New Courts, south side of the Parliament Square. At the latter a remnant of the city wall, erected in 1450, was laid bare; and in the mossy soil below it, about three or four feet under the foundation, were found a number of entire skeletons, showing that the ground had been used as a burying-place long before the wall was built.*

f, The ridge on which the Southern Districts are built.

B, Salisbury Crags and Arthur's Seat in outline, which are situated near the east end of this ridge.

k, The surface of the Meadows, a hollow filled with alluvial matter.

A little reflection shows that the three ridges *d, e, f*, owe their existence to the denuding action of a powerful current of water flowing from the west, and impeded in its course by the three trap hills A, B, C. The ridge *e*, on which the Old Town stands, affords a beautiful example of what Sir James Hall termed "Crag and Tail." The column of firm trap A, is about 900 feet long by 700 broad; and its summit projects about 80 feet above *e*, the highest part of the strata forming its tail. These strata, which, as formerly observed, are very soft, sink lower and lower as we proceed eastward, (see Fig. 17.) The marshy surface of the North Loch *h*, is about 280 feet below the summit of A, and the rock is perhaps 30 or 40 feet lower still. The ground on the west side of the Castle is probably 260 feet below A; and the Grassmarket, *i*, about 230 feet. Immediately eastward of the Castle, the sides of the tail ridge *e* are steep, and laterally as well as vertically quite within the shelter of the column of basalt. As the ridge recedes from this protecting column, its crest sinks lower and lower; its sides become flatter, and it loses itself in the general level at the Abbey, about a mile from its head.

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* An account of these relics was given in the *Scotsman* of 13th April 1833.

If we place a mass of tenacious clay, with a stone in the middle of it, in the current of a brisk stream of water, it will assume exactly the form of the ridge we have been describing. We shall find a ridge or tail of clay in the comparatively still water behind the stone, and tapering off, and losing height, as it recedes from the protecting object: on the opposite side of the stone also, where the stream is checked by its resistance, we generally find a lower and flatter ridge; but close in front, where the water, accumulated as it were, seeks a passage laterally, there is a hollow, and on each flank of the stone the clay is swept entirely away. The Castle rock in this case represents the stone, and the ridge under the High Street the tail. The valley which the Castle Bridge crosses, is the hollow worked out by the pressure of the water in front; and the North Loch on one side, with the Grassmarket and Cowgate on the other, which were once marshes, are the deep channels excavated on the flanks of the resisting object. The ridge in front is wanting, but we find it in connexion with the other heights.

The long swell *d*, on which the New Town stands, owes its existence to the Calton Hill, (C, Fig. 28,) which, checking the current of water in its progress eastward, protected the rocks from its more violent agency. There is a higher and sharper ridge on the east side of the hill, extending fully half a mile from the trap. Arthur's Seat and Salisbury Crags (B, Fig. 29) would in the same way occasion an abatement in the action of the current in front of them; and the protection thus afforded to a portion of the strata directly west from them, seems obviously the cause of the long swell *f*, between the Cowgate and the Meadows, on which the Southern Districts of Edinburgh stand, and which abuts, as it were, against the hill. The cavity of the Hunting Bog, between the hill and the crags, in the first place, and that between St Leonard's and the crags, in the second, would be hollowed out by the arrested current seeking a vent laterally.

The action of the current in hollowing out a cavity immediately in front of the resisting object, is shown in the diagram below.

FIG. 30.

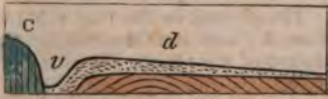


FIG. 31.

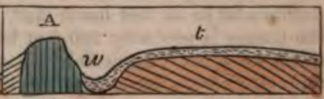


Fig. 30 is a section lengthways (east and west) through the ridge on which the New Town stands. C, the Calton Hill; *v*, the hollow in front of it; *d*, the ridge of the New Town. We see the protecting influence of the hill even in the thickness of the alluvium, marked by a dotted space. At Melville Street and Maitland Street, fully one mile west from the hill, it is only two, three, or four feet thick; at the New Club-Room, half a mile from the hill, it is six or eight feet thick; at the south-east and north-east corners of St Andrew's Square, 300 yards from the hill, I learn from Messrs Grainger and Miller, that the thickness is no less than twenty feet.

Fig. 31, a section east and west through the Castle. A, the trap rock of the Castle; *w*, the hollow in front of it, the bottom of which is about 100 feet below *t*, the swell of the ground towards the south end of the Lothian Road. The alluvium is very thick in the hollow *w*: on the west side it consists of soil and stones; on the east, of the debris of the trap. When the new bridge was building here, peat, with some small branches of trees, were found about 17 feet below the surface, showing that the morass of the Cowgate and North Loch had extended completely round the west side of the Castle.

The great current, acting of course with double violence on the flanks of these hills, tore up the strata to a greater depth; and there accordingly we find, in each case, either marshes or low grounds. Thus, Arthur's Seat has on one side the marsh *n*, (Fig. 28,) called the King's Meadow, 102 feet above the sea, and of unknown depth, which had evidently been continued at one time by *o*, to the Watering-Stone at the east end of the hill. On the south side it has Duddingston Loch *p*, the surface of which is 120 feet above the sea. The North Loch *h*, must in the same way have extended at one time along the North Back of the Canongate, by *m*. At the College Church it is 130 feet above the sea, and 70 feet below Prince's Street. Directly in front of the hill, we have a hollow which descends suddenly about 40 feet below Prince's Street; and even at this depth the alluvium is swept away, and the rock laid bare. Passing round the north flank of the hill, where the current had a clear sweep, it has hollowed out a cavity behind Greenside Place, about 100 feet lower than Prince's Street. The Castle is flanked by the North Loch *h*, and the low ground *i*, from the King's Stables to the Cowgate, which, as already stated, was once a marsh. Each of these depressions of the soil is extremely well marked, and the flanks of the hills above them are steep and bare, showing in the most distinct manner that these were the spots where the force of the current acted with the greatest energy.

The hollows of the North Loch and Cowgate are what the English geologists call "valleys of denudation;" but in reasoning on such cavities, scooped out by great currents of water, we must not forget that they are complex results, depending on local inequalities in the hardness of the rocks, as well as on the force and direction of the current.

We have other and even more palpable proofs of the existence of a great current from the west. In the Prince's Street Gardens, east as far as the Mound, masses of the trap of the Castle rock are found strewed over the surface, of all sizes up to two or three cubic yards. Hundreds of similar boulders are unquestionably buried in the soft silt of the North Loch. In opening up a deep drain at the east end of the esplanade, on the south slope, in 1830, six or eight blocks of the trap, from three to four feet in diameter, were found amidst the clay, within a very limited space. A large stone of the same species lay for many years near the door of the old Gaelic Chapel. In cutting away the soil behind the Advocates' Library, eight or nine years ago, two huge blocks were exposed, one of them a cube of six feet, which must have weighed about 16 tons. This was 1500 feet east from the Castle gate. Now, all these belonged to the basaltic clinkstone of the Castle rock; and the characteristic fact is this, that *while numbers of these masses are strewed over the surface to the eastward, none of any notable size are found to the westward,* beyond the line to which fragments falling from the rock, in the progress of disintegration, are carried. When deep trenches were cut, and spaces opened for streets, on the slope between *t* and *w*, about seven or eight years ago, I examined the ground repeatedly, and never saw a mass of the Castle rock equal to half a cubic yard, though travelled fragments of greenstone exceeding this size, from distant localities, and many large angular blocks of sandstone, were met with.

Distinct marks of the action of the current can be traced on the precipice which forms the north end of the hill, (at N, Fig. 24, page 54.) At various places, from 20 feet above the level of the garden, up to the Castle wall, the surface of the trap rock may be observed curiously smoothed and polished, and sometimes scratched horizontally. These *dressings,* as Sir James Hall termed them, can be seen to best advantage about three or four o'clock in a bright day, by the observer stationing himself on the cross walk, near the stone pillar, so as to catch the reflected light. In dull weather they escape notice; but when the light is strong, they are so distinct that every doubt is removed, and the experienced observer is instantly led to conclude, that the rock had been exposed to abrasion to the height of 100 feet above the surface of the gardens, and that this abrasion must have resulted from the motion of stones, gravel, or sand, borne along horizontally. As the rock is subject to disintegration, and portions fall off from time to time, these marks, of course, are only to be seen at particular parts, and not along the whole surface. On the south end of the rock, a few feet under the level of the King's Bridge Road, a projecting portion of the rock was laid bare, exhibiting the same traces of abrasion.

The currents of which we are speaking must have been *oceanic* currents, and the rocks in this quarter seem to have been exposed to their denuding action in two different directions. The first, from the north-west, had stripped off much of the upper strata, which were shattered and disrupted by *faults* and intruding veins and masses of trap. We see its effects in the humbled and rounded form of the north end of the Castle rock, (see Fig. 24,) which, as most exposed to its violence, has been worn down to the extent of 80 or 100 feet beneath the level of the south end: we see, too, that the strata have been torn away from its north-east side, (at E, Fig. 25,) where a westerly current could scarcely affect them: finally, we observe that the isthmus of sedimentary strata, connecting the Castle rock with the ridge under the Old Town, which should have been at the middle of its east side, if the denuding current had come only from the west, is in reality at its south-east corner. When this current ceased to act, the strata on which the New Town stands probably formed one irregular inclined plane to the esplanade, and prolonged again from the esplanade to the site of Heriot's Hospital. A second current, at a later period, from west, or west by south, scooped out the North Loch, and the hollow of the Grassmarket and Cowgate; and to the latter, the *dressings* on the face of the rock, the deposit of clay on the surface, and the distribution of the trap boulders, may be attributed.

Since these sheets were printed, I find that the quarry in the greenstone vein near Lochend, alluded to at page 27 as now open, has ceased to be worked since I visited it, and is now filled up.

I should have mentioned, that the section of the Calton Hill, p. 50, borrowed from Mr Webster, was a class section, produced by that able geologist when he was a pupil of Professor Jameson's.

LOWER BASIN OF THE FORTH.

My original object, as previously stated, was merely to describe Arthur's Seat and the Pentland Hills; but thinking it desirable to show the geological relations of these with the adjoining parts of the basin of the Forth, the following sketch of the district from the Lammermuir to the Ochil Hills was prepared. It is the result of a partial and hasty survey, and, with trifling exceptions, is derived from personal observation. It is necessarily incomplete in many respects, and probably includes not a few positive errors. In extenuation of its imperfections, I can only plead, that I had not time to make more careful researches myself, and that I have made the best use I could of the labours of others.

The district to which the remarks in the following sketch apply, is about forty miles in breadth from north to south, and nearly the same in length from east to west, comprehending the greater part of the counties of Edinburgh, Haddington, Linlithgow, Fife, and Kinross. Its southern boundary is the range of the Lammermuir and Moorfoot Hills, and its northern the Ochils. It constitutes three-fourths of what is called the hydrographical basin of the Forth.

The greatest elevation of the Lammermuir Hills within the district, is about 2100 feet above the sea; that of the Ochil Hills nearly the same; that of the Pentlands 1900 feet.

The Firth of Forth occupies a hollow in the middle of the district; but the geologist regards it merely as a lower part of the plain. The deepest part of the Firth, except a small depression at Queensferry, scarcely exceeds 20 fathoms, (120 feet,) or about half the height of the Calton Hill above its base on the south side. If the water, therefore, were withdrawn, the low shores of Fife and the Lothians, connected by ground so nearly of the same level, would present the appearance of a continued tract of carse land.

A striking uniformity will be observed in the courses of the rivers, which generally run in a north-east and south-west direction. See, in the map, the Avon, the Almond, the North Esk, the Tyne; and the Eden, the Orr, and Devon, in Fife. This results from two causes: the elevation of the ground, and the position of the strata. A stream rarely takes the shortest route to the sea, or flows down the steepest declivity; but, after escaping from the interior of the hills, and coming among the stratified rocks, finding the beds of very unequal hardness, it cuts a channel in the softer ones, and continues to run on the *edges* of these, till some obstacle compels it to turn laterally and cut across the strata. Having gained a lower level by this operation, it seeks out a new channel, as before, on the edges of the softer strata, till the elevation of the ground again forces it to make another transverse cut. Thus the Water of Leith flows parallel to Pentland Hills as far as Colinton, and at a higher level than that to which a course of the same length, directly away from the hills, would have conducted it. At Colinton it turns suddenly to the north-west, for half a mile; and here it has excavated a passage across highly inclined beds, and formed a deep and picturesque ravine. We have similar examples in the remarkable turn which the Avon takes about a mile below Linlithgow, in Bevelaw Burn, and elsewhere. It is probable, however, that fissures in the strata, produced by *faults,* have in some cases opened channels for streams, and determined their courses, in lines at variance with the direction of the strata and the declivity of the surface.

The rocks which present themselves at the surface, in this district, belong to the two great natural divisions of *sedimentary* or *stratified,* and *igneous* or *erupted* rocks; and they are all comprehended in the Transition and Secondary classes of Werner.

The Sedimentary Rocks may be conveniently divided into *five* groups or formations, beginning with the lowest.

1. *Greywacké and Clay Slate,* in strata nearly vertical.

2. *Old Red Sandstone,* resting on the edges of the greywacké and clay slate. The continental geologists consider this rock as a "newer greywacké;" and the term is sufficiently appropriate to what exists in the Pentland Hills; for it consists generally of a greenish or bluish-grey rock, composed of the detritus of the clay slate and greywacké, or of a conglomerate formed of rolled masses of the same materials, and has no resemblance to what is familiarly known by the name of sandstone. To avoid confusion, I have applied the word *conglomerate* to all the varieties of this rock in Pentland Hills—to the fine granular and compact, as well as that which consists of rolled masses.

3. Above this, we have a group corresponding partly to the "mountain limestone," partly to the "old red sandstone" of the English geologists. Both of these terms seem inappropriate here. The limestone occurs chiefly in thin beds, often widely separated from each other; and its aggregate depth, compared to that of the series associated with it, is so inconsiderable, that the term "mountain limestone" is altogether unsuitable. Besides, it cannot easily be separated, either from the coal measures above, or a rock corresponding to the old red sandstone of the English geologists below; and thus it wants the definite character of a distinct formation. On the other hand, the thick beds of sandstone in the lower part of the group are much more closely allied, in mechanical structure and mineral character, with rocks of the coal formation, than with the subjacent conglomerate, to which the denomination of "old red sandstone" cannot be refused. If the sandstone of the

Cairn Hills is classed as "old red sandstone," a different term should be applied to the conglomerate of Mount Maw and Habbie's How, which is entirely dissimilar both in substance and aspect. To separate the former from the rocks of the coal formation, which it closely resembles, (and with which it has been associated by other geologists,) and unite it with the conglomerate, seems inconsistent with sound principles of classification. On the other hand, the great depth of the coal series here, (extending to 5000 feet,) renders subdivision desirable; and the shell limestone supplies us with a well-marked line of demarcation. I have therefore ventured to apply the term "calciferous sandstones" to the series of rocks extending from the shell limestone downwards to the argillaceous conglomerate of the Pentlands. It corresponds in its lower part to the "old red sandstone" of the English geologists; in the upper, to their "mountain limestone," and to a portion of what is coloured as the "coal series" in Dr M'Culloch's geological map of Scotland. It consists of beds of sandstone, black and blue shale, some thin beds of clay ironstone and coal, and beds of limestone, the majority very thin, but one or two of which have generally a depth of 30 or 40, and in a few cases of 60 feet. This group is the chief repository of the beds and masses of newer trap (basalt and dolerite) found in this district.

4. The *Coal Measures*, or series of beds in which the workable seams of coal are usually found, resting on the "calciferous sandstones."

5. The "upper coal," or "flat coal" of Mr Bald, corresponding in position with the "new red sandstone" of the English geologists, but less recent, and to which I have ventured, though with some hesitation, to apply the name proposed by Mr Murchison, of the *Roslin Sandstone*.

The Igneous Rocks, as their name imports, are the product of fire, and have been partly thrown out above the sedimentary rocks, partly injected among them. In this district they all belong to the trap family, and may be subdivided into two genera: the *porphyry series*, embracing the clinkstones, claystones, and felspars of the Pentlands, Braid Hills, Garleton Hills, and the Ochils; and the *basalt series*, comprehending the newer greenstones and basalts, such as those of Arthur's Seat, Craiglockhart Hill, Corstorphine Hill, &c. These rocks are of different ages, as geologists express it; that is, they have been thrown out in succession, after long intervals. Their age, however, is less easily determined than that of the sedimentary rocks, among which the order of superposition supplies a clear and certain criterion of relative antiquity. In some instances we are able to fix the age of traps, by noting what beds have, and what have not, been disturbed by their intrusion; and when beds of one species are traversed by veins of another, we are sure that the latter are posterior; for veins are fissures in beds produced subsequently to their consolidation; and the minerals which have passed into and filled these fissures, must be newer than the beds which contain them.

The extent of these formations is shown on the map, which I offer merely as a rude approximation; but the relative positions of the rocks will be better understood from the sections.

Dr Macculloch estimates that the igneous rocks of both classes, trap and granite, do not occupy one-thousandth part of the superficies of Britain. In the district embraced by the map, they are much more abundant.

The greywacké, greywacké slate, and clayslate, of the Lammermuir and Pentland Hills, lie below all the other sedimentary rocks, and constitute what may be termed the fundamental rock of the district. Dr Macculloch has applied the designation of clayslate to this formation; but greywacké is the characteristic substance, though comparatively small in quantity. In the district to which my remarks refer, the rock is always in beds or strata nearly vertical; and, for the sake of brevity, I have generally used the term *vertical slate,* as descriptive of the whole.

GENERAL SECTION, No. I.

FROM SOUTRA HILL TO GLEN FARG, *along the line 3, 4, 5, in the map.*

THE section is not a straight line, but consists of two portions, which join at Arthur's Seat at an obtuse angle, and form together a line 42 miles in length. It is proper to state, once for all, that, in this and the other sections, the height is always on an enlarged scale compared with the length; and, as a consequence, the dips and declivities appear generally much steeper than they are in nature. I ought also to add, that the sections were hurriedly drawn, and with very little attention to the proportional elevations of the different localities.

The heavy black line, *a, b, c, d, e,* represents the shell or coral, or encrinite limestone, which the mining engineers consider as marking the lower boundary of the workable coal. Seams of coal are very often found below it; but it rarely happens that they are of sufficient thickness to repay the expense of excavation. A second bed of limestone is often found similar to the first, and at no great distance from it. Sometimes it is below the first, as at Burdiehouse; sometimes above it, as at Bowden Hill, near Linlithgow. Sometimes it is destitute of marine shells; sometimes it contains them. Sometimes, instead of two beds, there are six, eight, or ten; but in this case most of them are thin. The notched lines — — — — — mark some of the places where such beds are found.

m, The trap of the west Lomond Hill.

n, o, The series of traps and traptuffs north of Burntisland.

x, The height on which Craigmillar Castle stands.

The coal measures are coloured blackish-grey, and the calciferous sandstones, blue.

It will be seen that the coal measures, in this line of section, form three limited basins, or trough-shaped cavities. The most southern extends from Crichton Dean to Ford, *e* to *f*; the next from the Marquis of Lothian's grounds to the neighbourhood of Gilmerton, *c* to *d*. At Drum, and some other places near the northern margin of this basin *c*, the beds are nearly vertical, and have the appropriate name of *edge seams*. Towards the south margin *d*, the inclination is more moderate. In the middle are found a thick mass of strata, nearly horizontal, R, which at Edmonstone afford a bed of excellent coal. Mr Bald considers these as a newer formation, deposited after the other beds were tilted into their inclined position; and my own limited inquiries have led me to adopt his opinion. The third basin extends from about Lochgelly to the south side of the Lomond Hills. I have not examined this tract of country with any care, and I believe little or no coal is worked in it; but the limestone is found at its two extremities; and Dr Macculloch has marked it as belonging to the coal series, but with deposits of trap interposed, which probably break its continuity, and throw out all but the inferior seams.

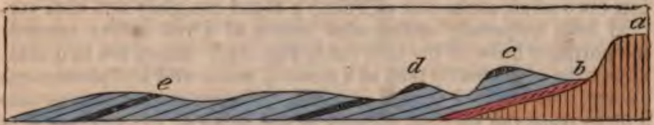
The deep series of strata, which I have named calciferous sandstones, underlie the coal measures. Where they are fully developed, the lower part consists chiefly of thick-bedded sandstone, not hard, generally of a red colour, with some little slate clay or limestone intermixed, but rarely with any beds of trap. In the upper part there are great deposits of black bituminous shale and blue slate clay, with thin beds of limestone and clay ironstone, occasional seams of coal, and often vast masses of trap. Its depth is very unequal. It is probably not more than 200 feet at Fala, and not less than 1000 between the west Lomond Hill and the Ochils. (See the Section.)

It is extremely probable that the two coal basins, *c d* and *e f*, were originally united, and have been separated in consequence of the mass of strata at the Roman Camp hill being forced upward by some agent operating at a depth below. The agent was probably trap injected among the strata, but not appearing at the surface. This subject will be adverted to afterwards.

Having premised this brief sketch of the section, a few details may be added respecting its more interesting parts.

FIG. 32.

SECTION FROM SOUTRA HILL NORTH-WESTWARD.



a, Soutra Hill, consisting of clay slate, intermixed with greywacké, in beds nearly vertical.
b, A red sandstone, dipping northwards at 10° or 12°.
c, Limestone found on a swell, 100 feet above a rivulet flowing northwards, about three quarters of a mile from *b*.
d, The same limestone, found about half a mile farther west.
e, The coral limestone, exposed in quarries on the road near Crichton Dean, about three miles from *b*.

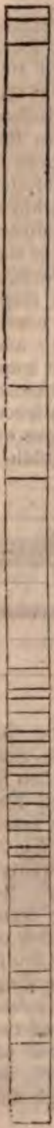
The Greywacké and Clay Slate.—The Lammermuir Hills consist chiefly of clay slate, with beds of greywacké intermixed. Here, and on Gala-Water, the direction ranges from N.N.E. to E.N.E.; the dip of the beds varies from about 50° N.W. to 50° S.E.; but a great proportion of it is nearly vertical. The clay slate is a soft substance, often scarcely distinguishable from the shale (or slate clay) of the newer formations: it is sometimes nearly black, with a glazed surface, sometimes red, but more frequently a bluish-grey. It occasionally contains much mica, and sometimes displays a curiously contorted structure: it is fissile, and may often be split into laminæ as thin as paper; but it is sometimes so loose and shivery, that a specimen larger than half-a-crown cannot be obtained. This soft slate is interstratified with a pretty hard bluish-grey rock, (the greywacké,) closely resembling the more earthy greenstones, hence generally called "whinstone" by the country people, and extensively used for building and road metal. It is in beds, from an inch to 40 or 60 feet thick, and has cross rents at right angles, or oblique to the plane of the beds, which divide it into irregular quadrangular or polygonal masses. If we compare this group with the coal measures, the hard rock represents the sandstone, and the soft slate the shale, of the latter. The alternations occur nearly in the same manner, and in both cases the transition at times takes place abruptly, but at times is effected by insensible gradations, so that we cannot say where the firm rock ends and the soft begins. Some large beds of true greenstone and porphyry, occur among the greywacké.

These hills have round and smooth outlines, with few precipices. Many of the valleys run parallel to the stratification, and were probably formed by the waste of the softer beds; but there are numerous short valleys, opening into larger ones, which are real *culs-de-sac*, terminating upwards in a rounded cavity, which forms a perfect semicircle, and in which there is no vestige of a stream. The principal valleys in these hills, such as those of the Gala and the Leader, run across the strata.

Calciferous Sandstones.—In descending the ravine near Woodcot, (two miles south-east of Fala,) I found the grey and blue vertical beds frequently mixed with others of a red colour towards the northern brow of the hill, (at *b*, Fig. 32.) There are two cataracts here of 60 and 80 feet, in a scene of much wild and picturesque beauty, and the rock is well exposed. The outermost beds deviate a little from the vertical, dipping to the north at 70°, and are of a brick-red colour and fine grain: nothing is visible but clay and soil for 150 yards beyond this, when we come to beds of sandstone comparatively level, but resembling the vertical beds in colour, hardness, and composition. They dip to the north at 10° or 12°, and alternate with others of a coarser grain, down to a mill half-a-mile below. In another burn which flows northward from Soutra toll-bar, I found the junction of the newer and older rocks. In the bed of this stream, about half-a-mile below the great road, there is a thin stratum of a sandy conglomerate *b*, of a deep red colour, consisting of rounded pieces of all sizes, up to six or eight inches diameter, encrusted in finer matter of the same kind. It rests on the edges of the vertical slate, which is here also of a red colour. The conglomerate is small in quantity, scarcely exceeding one or two feet in thickness, and lies generally in the hollows formed by the uneven edges of the greywacké. Above, it passes into red sandstone, by the gradual disappearance of the rolled pieces. The sandstone is always of a red colour, varying from coarse to fine-grained, and from a slaty structure to strata of two feet thick. I saw no shale amongst it. About a mile below the great road, a limekiln is seen at *c*, probably 100 feet above the rivulet, with numerous blocks of limestone, but none *in situ*. The same limestone is found in a field about a mile east of Fala, at *d*, on the road to Johnston Burn, but merely in loose masses. About three miles north-west from this, the great coral limestone, *e*, is exposed in a succession of quarries, near Crichton Dean and Cockum, where it is, I believe, fully 40 feet deep. The relative positions of these rocks, I conceive to be as shown in the Figure.

The Soutra limestone is a grey compact rock, closely resembling the great coral limestone; and it is possible that the detached portions of beds found at *c*, *d*, may be the extreme outcrop of the bed at *e*. The distance between the two, however, which is nearly three miles, is adverse to this supposition; and the similarity of aspect is a circumstance of small weight, since the same resemblance exists between the upper and lower limestones elsewhere. I saw no shells in the Soutra limestone, though I looked for them with some care.

THE COAL MEASURES.



Section of Edge Coal—387 fathoms in thickness.

This important group of rocks has the coral limestone for its lower boundary, not only here, but almost every where in Scotland. There is coal below the limestone, as already stated; but it is rarely worth the cost of working. The section on the margin shows the very irregular intervals at which the seams of coal are distributed among the other rocks. The black lines represent the seams of coal, the white spaces sandstone and shale.

It will be seen from the General Section, No. I., now describing, that this part of the coal-field forms two basins. From Crichton Dean the beds dip north-west, then rise again to the Roman Camp Hill, where the limestone is protruded through the superior beds. The inclination changes here again, descending towards Dalkeith, then rises once more to the north, and at Drum, Moredun, and some other places, the beds are seen nearly vertical. In the middle of the north basin, a considerable part of the surface is occupied by what is called the *flat coal*, (of Sheriff-Hall and Edmonstone,) the beds of which are nearly horizontal, and are believed to lie over the edges of the lower coal, which, from its high inclination, is called the *edge coal*. The latter is only worked near the two sides of the basin, as its depth in the centre is too great for mining operations.

We are indebted to Mr Bald and Mr Dunn* for an interesting account of this basin, of which I shall avail myself. From a section made obliquely, it has been ascertained that the *edge coal* strata have a thickness of 387 fathoms, measured at right angles to the planes of the beds. The *flat coal* has been pierced to the depth of 80 fathoms, making the thickness of the two series 467 fathoms. But some upper edge strata in the middle of the basin have never been reached, and are unknown, being covered by the flat coal; and if these were added, the entire depth, in Mr Bald's opinion, would not be less than 500 fathoms, or 3000 feet. This statement refers to the *north* basin, or that between the Roman Camp and Gilmerton.

The known *edge* strata consist of about 170 alternations of sandstone, shale, indurated clay, coal, and ironstone in small quantity, and (as we learn from Mr

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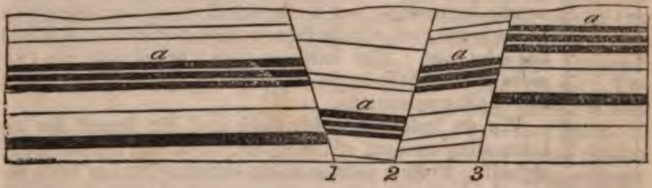
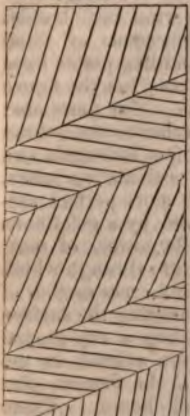
* Mr Bald's paper is in the Edinburgh Philosophical Journal for October 1827.—Mr Dunn's in the Transactions of the Natural History Society of Newcastle, vol. i. p. 165, published in 1831.

Dunn) limestone. The known portions of the edge and flat strata are 2800 feet deep, and include 33 *seams* (or beds) of coal, from nine inches to six feet thick, forming an aggregate depth of 109 feet. The coal, therefore, constitutes one *twenty-sixth part* of the series. Of the 33 seams, 31 are workable, that is, they are 18 inches thick or more. All these beds are bituminous, and belong to the two varieties of "cubical," and "splint" (or slaty) coal. There is none of the caking kind among them. The *faults* are numerous. Mr Dunn's plan of the Gilmerton field, exhibits eight within a space not exceeding a square mile. They run in various directions, but generally across the strata, and they shift portions of the beds in some cases 200 feet to the north or south of their former position. I am not aware of any of them being filled with trap. *Faults* are rents or dislocations of the strata, by which their continuity is broken, and part of them lifted up or thrown down; and when the rents are filled with solid rocks, such as sandstone or trap, they are called *dykes*. They are very instructive phenomena, affording striking illustrations of convulsions which have shattered the crust of the globe, and produced many remarkable changes on its surface. The figure below is reduced from one of Mr Buddle's sections in the Newcastle Transactions.



1, 2, 3, are dykes or faults. It will be seen, by comparing the four distinct portions into which the bed *a* is cut by the faults, that No. 1. throws down the strata through a certain space, which is about 150 feet; No. 2, throws them up nearly as much; and No. 3, throws them up about 100 feet farther. The faults are commonly named from the amount of the dislocation they produce. No. 2, in the section from which this is borrowed, is called the "twenty-five fathom dyke," and No. 3, the "sixteen fathom dyke." So numerous are these faults in some cases, that the same plate from which this is copied, exhibits *seven* within a length of two-thirds of a mile. Miners have found that, when a bed is cut off by a fault, its continuation is to be sought upwards or downwards, according to the direction in which the acute angle of the fractured strata points. Thus, when the miner comes to the termination of the beds *a* on the left, he finds that the dyke No. 1, cuts it off obliquely, and as the sharp angle of the beds point downward, he seeks the continuation below. Passing onward again through the second portion, he finds the acute angle at the fault 2, pointing upwards, and seeks the continuation above. This rule is said to hold universally. I have not seen its cause explained. In the Alloa coal-field, Mr Bald has described two faults, of which the one throws down the strata 700, and the other no less than 1230 feet. The rents constituting these faults, run nearly parallel to the Ochil Hills. A section of them will be exhibited afterwards. Here is a vast mineral mass, probably half a mile thick, or more, which is proved to have been either raised or depressed 1900 feet,* a change of position exceeding the average height of the Pentland Hills above the sea. According to Mr Bald, faults filled with trap dykes, very often leave the level of the strata on the opposite sides unaltered.



Perhaps the most extraordinary group of coal measures known, is at Mons in the Netherlands. It consists of no less than 114 seams of coal, including small and great.

The annexed diagram will give an idea of the singular contortions the beds have undergone. It is a section running south and north, across the direction, or line of bearing.†

If we suppose a hundred sheets of paper to be fastened together, a number of them black, but mixed with others of a brown and grey colour, and after being moistened, to be placed on edge, and gradually pressed down by a weight on their upper end, they would settle into zig-zag folds something like the above. We would thus have a lively image of the coal measures of Mons—the brown representing the sandstone, the grey the shale, and the black the coal. Sir James Hall employed a mechanical device of this kind very happily, to illustrate the contortions of the greywacké at St Abb's Head. In consequence of these contortions, says M. Burat, a perpendicular shaft may pierce the same bed three or four times!

Owing to the economical importance of coal, the groups of rocks in which it exists, have been more carefully examined than any others; but there is no reason to think that disruptions and dislocations will be found less abundant in other parts of the earth's crust, if it were as minutely explored. A good geologist has said that there is not a square league of surface in all England without fractures.‡

The coral limestone is thrown up at Gilmerton and Moredun;

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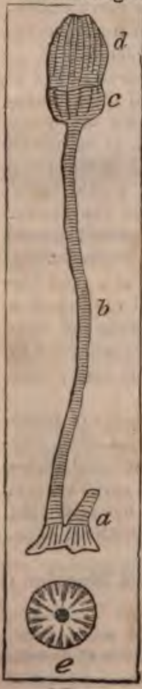
* Wernerian Trans. vol. iii. p. 123.

† Daubuisson, Traité de Geognosie, continued by Burat. Tom. 2d, p. 334. Paris, 1834. The Figure is incorrectly drawn. The angles formed by the folding of the beds, should not have been marked by transverse lines.

‡ De La Beche. Researches in Theoretical Geology, p. 45.

and below it is found another limestone, to which public attention has been strongly attracted by the interesting researches of Dr Hibbert. The latter is well exposed in the quarries at Burdiehouse, and in exploring the district around Edinburgh, in 1830, I found its prolongation in the water course at Moredun Hill, about three miles from Edinburgh, on the road to Libberton. At Burdiehouse, the bed dips to the south-east at 25°; at Moredun Mill it is nearly vertical; and here the space which divides it from the coral limestone, can be accurately measured, and rather exceeds half a mile. The upper limestone, however, being nearly level, allowance must be made for the unconformable portion of the two beds; and perhaps the real distance between them, or the thickness of the interposed beds, will not exceed 1200 feet, or a quarter of a mile.

The Coral Limestone.—The upper or Gilmerton bed, besides shells of various kinds, contains numerous fragments of fossil encrinites, marine animals resembling plants, and like plants fixed to one spot. They are of various forms and sizes; but the figure on the margin may serve as a type of the genus. The parts are:—*a*, The root by which it is attached to the bottom of the sea; *b*, the stem, several feet in length, and consisting of a vast number of articulating joints, similar to the vertical column in more perfect animals. These joints were covered by a gelatinous integument, having the contractile powers of muscle, and in the centre is an aperture through which the alimentary canal passed; *e* is a cross section of the column on a larger scale, exhibiting the surface of one of the joints; *c*, the pelvis, a cup-shaped cavity containing the body of the animal, in the middle of which is the mouth; *d*, the fingers, also composed of innumerable small bones. These fingers open out almost to a horizontal position, to catch the floating substances upon which the animal subsisted. When stimulated by the contact of these substances, the fingers closed, and pressed the prey downwards till it was seized by the mouth. From its shape, it formerly received the name of the stone lily. In one species, with numerous arms, it has been computed that there were 150,000 bones, most of them of course exceedingly minute. The roots of some species being united, formed a thin pavement, from which their stems and branches (says Dr Buckland) rose into a thick sub-marine forest. The bones in the limestone are replaced by calcareous spar. These organic remains are found both in older and newer rocks; but the limestone now alluded to, is characterised by the immense abundance of them it contains, in consequence of which it is



often named the encrinal limestone. An entire fossil encrinite is extremely rare, but the fragments exist in myriads. They are to be seen of all sizes, from a line to half an inch in diameter in Gilmerton quarry, and to an inch in Invertiel quarry; and are easily known by the aperture in the centre.[*] There is besides a great variety of shells, such as Nautili, Ammonites, Echinites, Orthoceratites, &c. The fossils are often confined to a single stratum of a foot in thickness, but sometimes they are distributed through several strata, or are abundant in the shale beds above the limestone. The strata are from half a foot to five or six feet in depth; but the most usual thickness is from half a foot to a foot and a half. The prevailing colour is a bluish-grey, but it has sometimes a tint of brown, or red, or black. It is generally compact, but sometimes highly crystalline, especially in the vicinity of trap rocks, as at Mr Marjoribanks' quarry near Bathgate. The cross rents are exceedingly numerous, and the strata being generally very uniform, the rock, seen at a distance, often presents the aspect of a wall of masonry in regular courses. The thickness varies from ten or twelve feet, (at Carlops,) to sixty at Silver Mine quarry, near Linlithgow; a part being always too poor for working. Of the sixty feet in the quarry last mentioned, eighteen are unfit for burning.

The Lower or Burdiehouse Limestone.[†]—This bed is twenty-seven feet in depth, and is disposed in strata which are about four and a half feet thick. It is of a bluish, blackish, or brownish-grey colour, of a compact texture, and a dull earthy aspect. It contains much carbonaceous matter, derived from vegetables. *Plants.*—The fossil plants are of several kinds, chiefly tropical, either of terrestrial or fresh water origin, and similar to those of the coal measures. The more remarkable are, three varieties of Sphenopteris (ferns) and several of Lycopodiaceœ (club-moss;) these are abundant; and along with them are a few relics of the Stigmaria, Sigillaria, Equisetum, (horse-tail,) Calamus, (reed,) and Cyclopteris. *Animals.*—The animal remains are those of fish; 1st, the teeth and jaws are found of a large predaceous fish fifty or sixty feet long, the Megalichthys Hibberti, allied to the crocodile family; 2d, the bones and scales of another large fish, the Gyracanthus, similar in its osteology to the Cestracion, or New Holland Shark; 3d, entire skeletons of several smaller fishes, on which Monsieur Agassiz has bestowed the learned names of Palœoniscus, &c. Besides these, there are myriads of extremely minute shell-fish, named Entomostraca. They are microscopic animals, which for size may be compared to the heads of pins, the smallest being like a mite, and the largest only about one-twelfth of an inch in length.* There are probably few fragments of the limestone as large as the fist, in which some of these animalculæ may not be discovered, after the surface has been some time exposed to the weather; and in some portions of it they are so numerous, that the rock appears as if powdered over with objects like the roe of a herring. In these bodies, minute as they are, the organized structure can be observed with a glass of no great power; and with a good microscope, an exterior shell or covering, claws, eyes, and slender feelers or antennæ, can be perceived. Nothing, perhaps, is better calculated to give us a conception of the refined and delicate process by which foreign substances are mineralized in rocks, than the fact that such peculiarities of structure can be ascertained in these very minute fossils, which have lost every trace of animal matter, and consist merely of atoms of limestone! Living beings of similar size, and somewhat analogous structure, (Entomostraca,) are found in fresh water lakes which abound in decaying vegetable matter, and may be seen at those shallow parts where the bottom passes into the state of soft mud in summer. Dr Knox has found them in multitudes in the lake of Lochmaben, where they serve for food to a fish called the Vendace. Dr Hibbert has no doubt that his fossil animalculæ were the food of the Palæoniscus and other smaller fish in the ancient Burdiehouse estuary or lagoon, as the latter in their turn were devoured by the lordly aristocrats of the pool, the Megalichthys and Gyracanthus! That one or both of these dined on their smaller brethren, is rendered certain, not merely from the structure of their teeth, but from the *coprolites*, or fossil dung of the larger finny tribes, found abundantly in the quarry, and in which fish scales are generally a constituent. The fact is curious, and shows through how many channels we can ascend to a knowledge of the structure and functions of extinct animals, of which we have nothing preserved but a mere image or cast in stone! Dr Hibbert concludes, that the Burdiehouse limestone is a *fresh water deposit;* that is, a mass, the materials of which had been dissolved in fresh water, and precipitated by slow degrees, entombing numerous plants, and the remains of animals. He rests this conclusion on two facts; first, the entire absence of marine shells and corals; secondly, the presence of thousands of fresh water plants, which are in most cases so entire and perfect, as to render it improbable that they were borne along by rivers or torrents from a distance, and subjected to the chafing of the tide. At the same time, the existence of the teeth and jaw-bones of the Megalichthy, in the rock, shows that the sea had at least occasional access to the place. Mr Horner, in a paper lately read before the Royal Society, controverts Dr Hibbert's opinion; and contends, I think on probable grounds, that the rock is of marine origin. We may therefore infer, that at a remote period in the history of our planet, what is now the Dalkeith coal-field was a bay of the sea, in which huge predaceous fishes, partaking of the nature of a crocodile, gambolled, as the alligators at this day sport in the lagoons of the West Indies, while tropical plants flourish in the vicinity. The remains of this large fish chiefly met with, are the teeth, some of which, three inches long, have the enamel quite perfect, and exhibit their natural colours. The same relics have been found by Lord Greenock among the coal strata. Indeed, it is admitted that the zoological character of the deposits, had undergone very little change from the earliest periods to the era when the magnesian limestone was formed.* After the Burdiehouse limestone rocks were deposited, alternating beds of sandstone and shale, with seams of coal, were formed in the same waters from the spoils of the mountains and forests. At a still later period, the coral bank of Gilmerton arose from the labours of zoophytes, encrinites, mollusks, &c., above which were successively deposited the numerous beds of the Coal Measures and Upper Coal. Subsequently to this, the whole series of rocks were lifted out of the waters by a subterranean movement.

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[*] On the form, structure, and functions of this curious animal, see Professor Buckland's Bridgewater Treatise; vol. i. p. 421.

[†] This description is entirely borrowed from the excellent Memoir of Dr Hibbert, published in the Transactions of the Royal Society of Edinburgh in 1835.

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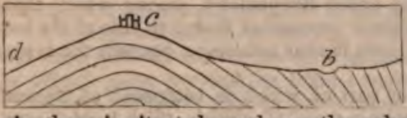
* Figures of these microscopic shells may be seen in Dr Hibbert's Memoir; and some from the Paris basin are given by Mr Lyell in the 4th vol. of his Principles of Geology, p. 123, Third Edition.



The rocks immediately under the Burdiehouse limestone, are found almost vertical in the stream between Moredun Mill and Little France, below which the channel, as far as I have examined it, is covered with gravel. From an inspection of the ground here it seems reasonable to conclude, that these strata become less and less inclined from a line about 500 or 600 yards south-east of Craigmillar Hill, and that the fine ancient ruin there is situated nearly on the culminating point, as in the above diagram, where *c* represents Craigmillar Castle, and *b* the burn on its south-east side, which falls into the sea between Joppa and Fisherrow. Pits were opened four years ago in the soil behind the smithy, a quarter of a mile north from Little France, and I observed the rock to dip S.E. about 12°. At the Castle, the rocks are nearly horizontal. Within the grounds, and in the little copse eastward of the farm-house, they are seen dipping S.E., E., and N., and huge masses of 10 or 15 tons are lying strewed over the surface as if the ground had been convulsed, and the superior beds disrupted by forces acting from below. It is probable that the strata have been raised up and bent in this manner by the agency of trap rocks, a continuation perhaps of those of Blackford Hill. The rock under the Castle consists of a grey or reddish-grey sandstone, without any shale, which from its position I refer to the calciferous sandstones. It is seen dipping gently to the north at Cairntow, *d*, and to the north-east in Sir Robert Dick's grounds, near the Loch and the Railway. It appears to pass under Arthur's Seat; but the discrepancy between it and the rocks of the hill, in direction and inclination, indicates the probability of faults existing here, which render the relations of the two series of beds uncertain.

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* De La Beche, Manual, Pp. 490. The magnesian limestone is newer than the coal.

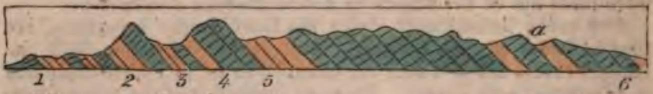
We cannot know positively the arrangement of the strata under the Firth; but the relations of the rocks on its opposite sides, and the detached portions seen in the islands, lead us to infer that from Leith to Burntisland it would be nearly as represented in the GENERAL SECTION.

At Burntisland we have a remarkable series of rocks, *n*, *o*, referable to the calciferous sandstones, which I shall briefly describe.

SECTION S. AND N.

FROM BURNTISLAND TO ACHTERTOOL.

FIG. 37.



The trap rocks are cross-hatched, the sandstones left white.

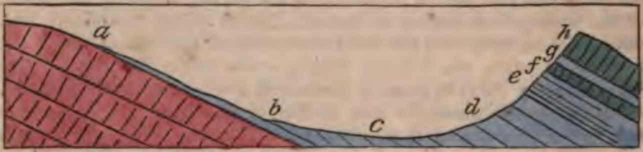
1. Several beds of trap under Burntisland, among which there is one bed of sandstone exposed at the north side of the harbour. I believe there is also sandstone beneath the lowest trap visible here.
2. Bins Hill, the upper part of which is composed of traptuff. This rock rests upon a mass of whitish, thick-bedded sandstone, probably 200 feet in depth, which contains at least two beds of trap.
3. Beds of sandstone at the back of Bins Hill, reaching nearly to the summit. These contain a bed of limestone, about six feet thick; it is in laminæ from two to ten inches thick, of a bluish-grey colour, compact, without any visible shells or plants. One thin layer of the limestone is black.
4. Dunearn Hill, is composed of a succession of beds of basalt, mostly in columns, from eight to fifteen inches diameter. The beds dip to N. or N.N.W., probably about 25° on an average. The whole rest on traptuff, and this again on sandstone.

5, 6, Sandstone is found at the back of Dunearn Hill, then a bed of traptuff, then another bed of sandstone, after which I saw no more of the sedimentary rock till I came to Achtertool, (*a*,) near which are two large beds of sandstone, divided and surmounted by traptuff. About a mile and a half beyond Achtertool, the face of the country sinks, and loses that irregularly indented outline which the trap rocks give it, and I conclude that they terminate about Lochgelly. There is a lime quarry a little to the eastward of that loch, which I did not visit.

From Dunearn Hill northward, I saw only four beds of sandstone, which were perhaps 100 feet thick each. There are at least two beds between Dunearn Hill and the traptuff of Bins Hill; there are three beds between the latter and the trap on which Burntisland stands, and one in the harbour; in all ten beds. The sandstone is of a yellowish white, and generally in thick strata, with little shale. The dip is from N.N.W. to N., and from 10° to 25°, probably averaging 15°. The horizontal distance is fully four miles, or 21,000 feet, and the real depth of the beds at right angles to their planes, will be at least 5000 feet, of which 1000 perhaps consists of sandstone, and 4000 of trap, or traptuff; the latter rock is very abundant, and has often a base of wacké. As the sandstone, however, is always the lower and less conspicuous rock, it is probable that several beds of it escaped notice, and its actual thickness may exceed what has just been stated. Of the trap beds some are of a dark compact basalt, with grains of olivine; others, along with grains of olivine, contain large crystals of a dark mineral, which is probably augite. The trap invariably forms the summit of the highest hills, such as Dunearn Hill, and another about two miles eastward. This fact is instructive, as it consists well with the hypothesis, that the present condition of the surface is partly the result of the mechanical action of the sea, (under which the whole had been once buried,) and the meteoric action of the atmosphere. In the inland parts, we find the firmest rocks projecting beyond the other strata. Next to them in prominence we observe the traptuff, which is *next in tenacity;* and we find the sandstone, the *most fragile,* in the lowest and most sheltered situations, generally indeed protected by a covering of one of the other rocks. The whole district presents a series of small crags, with their steep sides to the south, and always crested by beds of trap. The small elevation of the rock on which Burntisland stands, may be explained by assuming that the land rose, not suddenly, but gradually, from under the water; and the rocks at Burntisland, being the outer portion, would be subjected to the violence of the tidal currents for ages after those in the interior were dry. The sandstone (under Bins Hill) which covered the Burntisland trap, and the sandstone which probably underlies it, would be undermined and washed away by an agency which did not touch the rock of Dunearn Hill; and the trap itself would suffer as the process of denudation went on, the outer portions falling down when their support was removed, and the interior parts now uncovered, yielding to the force of the waves.

The traptuff of Bins Hill has the usual aspect of that rock. It consists of a soft earthy crumbling base, in which are embedded thousands of fragments from the size of a pea up to three feet in diameter. These fragments are chiefly angular, and the rock is therefore more properly a breccia. Most of them are of the same materials as the base, but some are of a basalt or greenstone of darker colour and firmer texture. A little beyond Achtertool, the trap crags and hills disappear, and the country continues comparatively level till we come to the Lomond Hills. I intended to examine this tract with greater care, but have been unable to find time. I infer, however, that the coal worked on it belongs to the lower beds of the coal measures, partly from the position of the limestone at its two extremities, partly on the authority of Dr M'Culloch's map, and the facts supplied by Mr Landale in his map sections and survey noticed hereafter. There is but little rock visible, at least on the road from Kirkcaldy to Leslie. At Glassly, near the south part of the East Lomond Hill, there is a thick bed of limestone, with a few shells. It is blue coloured, hard, and in strata from half a foot to a foot in thickness. I have assumed that it does not pass under the trap which crowns the hill, but I did not visit the north declivity where it should be looked for. I passed through Glen Farg southwards, and clambered up the precipitous northern front of the West Lomond Hill; and the following is the result of my observations.

FIG. 38.



a. Beds of amygdaloid, porphyry, clinkstone, claystone, felspar, and greenstone, dipping S. or S.W., at angles varying from 15° to 25° at the north side, and from 5° to 15° at the south. These are well exposed in Glen Farg. The general dip of the beds of the Ochils, according to Mr Mackenzie, is to S.E. (Wernerian Memoirs, vol. ii. p. 1.)

b, c. A bed of sandstone, probably 600 feet thick. It is sometimes in thick strata, but much of it exhibits a division into very thin laminæ, bearing in some parts a faint external resemblance to gneiss. This laminated structure, no doubt, arises from the mica which abounds in it. When examined with the lens, it is seen to consist of red, blue, and white grains, the latter of quartz and the others of clay. At the bottom, it passes into a conglomerate of small thickness, composed of rounded pebbles, and containing thin bands of limestone in nodules. It rests on the rock of the hills. Near Blairhead farm I traced it in a rivulet, dipping S.E. at 8°; but I did not see the actual junction of the rocks.

d. A white sandstone in thick strata. It is rather soft, but harder beds are intermingled, two of which project through the debris on the precipice. It displays the diagonal lamination, and in weathering, rounded holes of six, twelve, or even eighteen inches diameter, are formed in it. This sandstone is probably 300 feet thick, and I saw no shale intermixed with it. The dip of this and all the superior beds is S. or S.S.E., about 7°.

e. A series of beds consisting of, first, Black shale, with bands of clay ironstone, a red ochrey clay, and a little coal, in all about 50 feet.

Then, two beds of yellowish-white sandstone, about 80 or 100 feet thick, harder than the large beds below.

f. A dark crystalline greenstone, in tabular masses.

g. Other beds of yellowish sandstone, which are quarried on the east side of the summit.

h. A cap of basalt, probably 250 feet thick, forming the summit of the hill.

The West Lomond Hill is said to rise 1280 feet above the sea, and probably has an elevation of 900 feet above the valley which divides it from the Ochils. Boulders of greenstone of all sizes, up to 20 tons weight, are strewed over the high muirland surface eastward. They are not much rounded. Of the basalt there are few, probably because owing to their greater brittleness they break in the course of transportation.

The great mass of sandstone under the Lomonds, I refer to the group of calciferous sandstones. The true old red sandstone, a conglomerated or brecciated rock, passes under the Ochils at this part of the chain.

General Section, No. II.

FROM GIFFORD TO DOLLAR, *along the line 6, 7, in the map.*

Nearly a mile south from Danskin, and four miles south from Gifford, beds of greywackė, *w*, highly inclined, are exposed in a rivulet near the great road which crosses the hills. The outer portion of this formation, consisting of blue micaceous clay slate, dipping northward at 50° or 60°, can be traced over 500 yards to a point near Danskin. Here it is succeeded by a micaceous sandstone, of a deep red externally, but lighter within, in thick strata, but subdivisible into very thin laminæ, and dipping northward at

45°. I traced it for 600 yards in a deep wooded ravine; and as it is visible at Waldean Farm, its thickness probably exceeds 1500 feet. Into part of the grounds along the water-course northward, I could not procure admission; but at Yester House, and close to Gifford, I found a reddish-white sandstone dipping N. at 15°. The shell limestone *f*, appears within a mile of East Saltoun, in a nearly horizontal position. On the northern declivity of Falside Hall, between Ormiston and Musselburgh, (a position corresponding to *g* in this section,) sandstone and shale are exposed at numerous points, dipping N.W. from 10° to 25°. Mixed with them are bands of clay ironstone, and the outcrop of twelve or fifteen seams of coal, may be traced in the ditches at the road-side. Coal is or has been worked at many localities betwixt Musselburgh and Ormiston. From Musselburgh eastward, the coal strata are seen repeatedly on the beach. They dip W. or W.N.W. at 10° or 12°, and they retain this dip to Aberlady, with one or two trifling local exceptions, where the inclination is reversed. A large trap vein is seen at Morrison's Haven, (see the Section,) cutting the coal strata at right angles. It is supposed to be a continuation of the dyke which was quarried at Lochend, and at Broughton Street, Edinburgh; and it is seen at various points of the coast eastward to Bogle Hill, near Long Niddry, where it is displayed on a magnificent scale. It is nearly 150 feet broad here, and at low water can be traced forming a shoal for more than a mile to the westward. It consists of a fine-grained greenstone of a light colour, divided by rents both longitudinally and transversely. The sandstone and shale of the coal measures may be seen on both sides, partially altered and hardened by contact with it.

At Soutra the calciferous sandstones are found resting on the ends of the greywacké; but at Gifford we see a gradual transition from the vertical stratification of the older rocks on Newland Hill, to the horizontal stratification of the limestone at East Saltoun. On the most moderate calculation, the depth of the beds from the limestone to the clay slate at Danskin, cannot be less than 3000 feet.

The trap seen at *r*, in the bed of the Forth, (see the General Section,) is that of Inchkeith. This island consists of beds of sandstone, shale, and trap, dipping E.N.E., at 35° to 50°. It may be considered as a detached portion of the strata seen betwixt Kinghorn and Kirkcaldy. From the order in which the rocks present themselves at Kinghorn, it may be safely inferred that the shell limestone crops out at *e*, a little to the eastward of Inchkeith.

The rocks at Aberdour are described in the Coast section. The coal measures begin two or three miles eastward of Dunfermline, and the limestone is thrown up again three or four miles to the westward of that town. In a deep ravine at Saline, sandstone and shale, with some thin seams of coal, are found in horizontal beds, covered by a mass of porphyritic trap. In the upper beds the sandstone passes into a rock intermediate between a sandstone and a traptuff. On the west side of these hills are placed the coal-fields of Blairengone and Clackmannan, which I have not attempted to distinguish, as I do not know their geographical boundaries. The limestone which crops out beneath the coal measures at Blairengone, *b*, is not seen under the Alloa coal-field; but Mr Bald thinks it exists there, perhaps as at *a*, and it comes to the surface at Cambus, about two miles east from Stirling. In a brook half a mile east of Harvieston House, I found numerous strata of sandstone and black shale, much disturbed. They dip away from the Ochils at various angles, those below from 25° to 40°; but on the face of the hill, at the more elevated spots, they are inclined at 50° or 60°, and some absolutely vertical. At the height of probably 400 feet, there is a thick bed of greenstone running parallel to the hills, above which sandstone and shale appear as before, with vegetable impressions. Among these strata is a bed of compact limestone, probably 20 feet thick, (without any shells, so far as I could see,) a fact which tends to confirm Mr Bald's opinion, that the limestone exists under the coal at Alloa, though not visible. A little beyond this, at the height of probably 500 feet above the Devon, the sedimentary rocks terminate, and are succeeded by the trap of the hills, which Mr Bald describes as consisting, at Alva, of greenstone, clinkstone, clinkstone porphyry, and sienite, in beds dipping to the south at 60° or 70°. The bed of greenstone, 100 feet thick, mentioned by him, which is nearest the coal, is perhaps the same which I saw in the brook three miles eastward. Mr Bald makes the instructive remark, that the trap of the Ochils, which has tilted the strata of the Coal Measures, has not affected the quality of the coal, while the greenstone of Law Hill, near Dollar, has destroyed it; and he hence infers, that the latter had been forced up in a fused, or at least a very hot state, while the trap of the Ochils had lost its high temperature, before it underwent the upheaving movement which raised it to its present elevation.*

GENERAL SECTION, No. III.

FROM DUNBAR TO BORROWSTONESS.

The white spaces denote beds of sedimentary rocks; the cross-hatched spaces, trap; the heavy black lines, the upper limestone; and the position of the lines marks the dip of the rocks to the west or east. Horizontal lines indicate that the rocks have no dip, or that the dip is north or south. The diagram does not exhibit the *number* of the beds; and from the necessity of crowding so many objects into so small a space, the inclination is unavoidably represented as much greater than it generally is in nature.

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* See Mr Bald's interesting paper in the Wernerian Transactions, Vol. iii., p. 123, from which, and from verbal communication with himself, the substance of what is stated in this paragraph has been derived.

This section follows the line of the coast, and is about fifty miles in length. It would have been more convenient in some respects to reverse its position, placing the east end on the left, and the west on the right. In this way it would have been seen as it presents itself to the eye of a person sailing along the south side of the Firth, at a small distance from the land; but I preferred the opposite arrangement, as more conformable to the manner in which maps are usually placed with reference to the observer, and also as affording a readier means of comparison with the section of the Fife coast.

I have examined, in a general way, the whole coast from Canty Bay, three miles east from North Berwick, to the mouth of the Avon, beyond Borrowstoness, except about half a mile at the west side of Dirleton Common. From Canty Bay to Dunbar, the slight notices inserted are derived from Professor Jameson's paper in the third volume of the Wernerian Memoirs.

From Dunbar to North Berwick, there are numerous alternations of red sandstone, white sandstone, trap, and traptuff, nearly all dipping to the E., S.E., or N.E. The traps consist chiefly of basalt and amygdaloid. The portion of the line extending from North Berwick to Canty Bay, opposite the Bass, presents a curious display of traptuff, *p*, *q*, which merits notice. The base is of a dark or light grey colour, with shades of blue, or red, or brown. It seems to consist of the materials of trap, with a little sandstone and shale, sometimes ground down to sand, and forming a tolerably compact substance; at others composed of small angular fragments, of the size of peas, and very feebly coherent. It is uniformly stratified; and the strata often consist of layers, half an inch or an inch in thickness. The embedded fragments are of all sizes, up to two or three yards in length, and generally angular; four-fifths of them are of the same materials with the base, consisting of masses of older, inclosed in a paste of newer tuff. The others consist of basalt or porphyry, with a few of shale, sandstone, and limestone. There is a lime quarry near the shore, one mile east of the town, and for 100 yards opposite the quarry, the embedded masses are nearly all limestone, of various sizes, up to two or three feet in breadth. About a mile farther east, there is an assemblage of masses of dark firm trap, heaped together, on a space 100 feet long by 40 broad, as if they were the ruins of a rough sea bulwark. They are of all sizes, up to eight or nine feet in diameter. These, on careful inspection, prove to be nothing else than embedded masses, three-fourths of the soft paste which enveloped them being washed away. The same stratum or lamina of tuff varies much in thickness, being perhaps half a foot, a foot, and two feet thick, all within a length of six or seven yards. The base is traversed in opposite directions by veins of spar, half an inch or one inch broad, and which may often be traced for fifty yards, without intermission. According to Boué, they consist of lamellar or fibrous carbonate of lime. Among the finer tuffs, at one place where the beds formed a shallow natural cavity thirty or forty feet broad, I observed two beds of compact limestone, each three or four inches thick, divided by layers of shale—a fact tending to show, that the beds or laminæ of tuff had been slowly deposited, since the interval betwixt the deposition of two was long enough to permit these limestones to form. About half a mile east of the town, there is an isolated mass of dark porphyritic basalt, 50 feet long, 30 broad, and 20 high, projecting through the surface of loose sand. I have little doubt that the lamellar tuff, which is seen a few yards from it, once completely enveloped this mass, but has been gradually washed away, leaving it uncovered, as we now see it. For a considerable way eastward of North Berwick harbour, the tuff is in thin laminæ, very regularly disposed, having only a few small embedded pebbles, and so much resembles slate clay, that one can scarcely avoid regarding it as formed by a similar process. It has been said, that if trap be analogous to granite, we ought to have a slaty trap resembling gneiss; and, in point of fact, the laminated tuff here is no unapt representative of the primary stratified rock alluded to. From its structure, it might be inferred to be a sedimentary rock, formed from the detritus of previously existing traps; but similar appearances might perhaps result from the deposition of volcanic sand, ashes, and fragments, falling in water, and distributed by tides or moderate currents. The dip of the stratified traptuff is sometimes west, more frequently east; but the direction is pretty uniform, averaging about N.N.E. The first sandstone appears at Canty Bay, opposite the Bass. I did not visit this singular islet; but, according to Boué, it consists merely of a "superb mass of clinkstone."

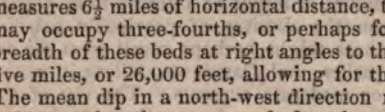
About a mile east of North Berwick, at *q*, there is a bed of fœtid limestone, about 40 feet thick; but the upper half consists chiefly of calcareous shale. It contains no shells. There are portions of limestone entangled among the trap beds to the west of North Berwick, some of them very much indurated.

From North Berwick westward to Aberlady there is another great display of trap rocks. At the harbour there are three thick beds of trap, and between the first and second there is a bed of the same loose red traptuff, which underlies the lowest, and is seen to the eastward. On the west side of the harbour the red lamellar tuff re-appears, and is succeeded by a series of rocks in the following order:—1. A trap of a deep blue colour, apparently with base of clinkstone. 2. The same rock, containing crystals of felspar, and assuming the character of an amygdaloid: this continues for a mile or more. 3. A basalt in small columns, seen in a conical hill 100 feet high, near the beach. This is opposite the islet of Fiddra. 4. We have a light-grey greenstone, curiously variegated, presenting large patches of light-bluish grey or yellowish-grey, often one or two feet broad, consisting apparently of compact felspar, parted from each other by numerous parallel streaks of deep brick-red, beautifully waved like the shading of coast-lines on a map, and the whole surface sometimes divided into large compartments by thin veins of white or red spar. 5. A tuff, apparently of claystone, sometimes assuming the character of a porphyry. It is red-coloured, reddish-white, or mottled, and is in large horizontal beds. This is about Glen Chair, three miles west from North Berwick. 6. Some beds or layers of sandstone, shale, clay ironstone, and limestone, nearly horizontal. 7. This is followed by a vast bed of dark greenstone, in irregular columns, from one to two feet broad, which continues for half-a-mile, with portions of sandstone and limestone amongst it. With the exceptions mentioned, most of these rocks dip north-west about 10° or 12°. Of the rocks along the coast from this point (a little south-west from Eyebrow Islet,) round to Aberlady by the coast, I had only a hasty inspection, under very unfavourable circumstances. Where the sands did not cover the surface, the rock was chiefly trap, with some sandstone, shale, and limestone, dipping almost uniformly to the north-west. Of the coast section, from North Berwick to Goolan Point, which measures 6½ miles of horizontal distance, the trap rocks and traptuffs may occupy three-fourths, or perhaps four-fifths. Measuring the breadth of these beds at right angles to the direction, it will be fully five miles, or 26,000 feet, allowing for the part that is horizontal. The mean dip in a north-west direction may be assumed to be 7°, and supposing there are no faults, the true thickness of the beds will be about 3000 feet, of which 2200 may consist of trap and tuffs, and 800 of sandstone, shale, &c.

From this part of the Section it will be seen that North Berwick stands on the anteclinal line, or the axis from which the beds dip away in opposite directions.

North Berwick Law.—This singular hill rises to the height of 940 feet above the sea, or probably 800 above its base. From any distant point to the westward, its figure is precisely that of a pyramid. The diagrams below give an ideal view of its structure, for the perfect accuracy of which I will not vouch, as it was derived from a hasty examination in one forenoon.

FIG. 39.



This is a section of the hill in an east and west direction.

a, A bed of reddish-brown fine granular traptuff, seen at the bottom, and well exposed on the south-west side, where it forms a terrace projecting 200 feet from the mass of the hill.

b, b, Clinkstone porphyry, which is apparently in beds dipping east at 12° or 15°. The beds are in laminæ from half an inch to two inches thick, parted by fissures which are nearly at right angles to the plane of the beds.

c, The summit, where the porphyry appears somewhat changed in character, presenting crystals of augite, and passing into what is technically a greenstone.*

d, The eastern declivity, or tail of the hill, which is covered by a thick coat of earth, is saddle-shaped transversely, and presents smooth outlines in all directions.

Fig. 40.

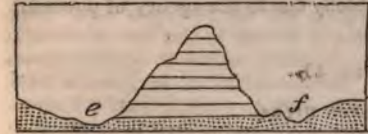


Fig. 41.

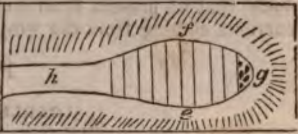


Fig. 40, is a section of the hill south and north, and Fig. 41, a ground-plan or miniature map, exhibiting the form of the hill on the horizontal plane.

e, A hollow on the north flank of the hill.

f, A similar hollow on the south flank.

g, A similar hollow on the west side.

h, The tail, a narrow but well-rounded ridge, with the hollows *e*, *f*, continued on its north and south sides.

The breadth of the hill, from *e* to *f*, probably does not exceed 1200 or 1500 feet; its length in the other direction, to the point where the tail descends to the common level, may be about a mile and a half.

North Berwick Law presents a beautiful example of crag and tail. The declivities, on all sides except the east, are steep, and consist of bare rocks, with mere patches of soil at intervals. In this feature, in the long tail stretching right eastward, and in the depression round its base, on the south, north, and west sides, it is exactly the counterpart of the Calton Hill and Castle Hill. Two hypotheses may be adopted as to the origin of the hill. We may suppose that the traps of which the principal mass consists, were formed at a depth under the surface, and that it was afterwards pushed up by a movement from below, like the granite of Goatfield in Arran; or we may suppose that the trap was injected, where it now stands, among sedimentary rocks, which have since been washed away, leaving the pyramidal mass as a monument of the wondrous changes effected by diluvial action. Its position close to or upon the anteclinal line, shows that the rocks here have experienced an upheaving movement; but whether the hill merely participated in the upheaval along with the adjoining district (including the Garleton Hills,) or whether a more limited movement separated its base from the surrounding strata, and forced it upward to a greater height, is a point which cannot be determined without a very careful survey of the adjacent country. If it contained masses of greywacké or other inferior rocks entangled in it, like the Hill of Kinnoul, the evidence of special and limited elevation would be strong. That the traptuff of its base is essentially of the same nature with that on the neighbouring coast, is a presumption in favour of the opposite opinion. But whether elevated in common with the surrounding district, or as a detached mass, there is no doubt that its present form is chiefly due to the agency of powerful currents coming from the west.*

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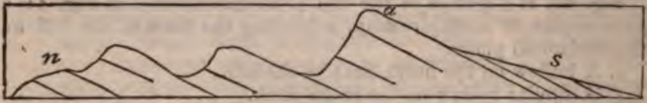
* Professor Jameson's Paper on the Geology of East-Lothian, 3d vol. Wernerian Memoirs.

FIG. 42.

GARLETON HILLS.



The above is a section in a south and north direction.

a, Yellow Crag.

s, The south side, where the trap is covered by the Calciferous Sandstones.

n, The north end towards Drem Toll.

These hills lie about a mile north of Haddington. They consist of claystone, of a yellow, red, or grey colour, generally of an arenaceous texture, so as to resemble sandstone at many places. It passes at some parts into clinkstone, of a bluish or greenish-grey colour, and glistening aspect. It undergoes great changes from weathering, and to a great depth: the grey and yellow portions become deeply streaked with red and white; and the outer part of the rock, divided by fissures parallel to the surface, assumes a slaty or laminated appearance. Portions of the northern precipitous front of Yellow Crag, seem to have separated from the mass of the hill in this way by vertical rents, and the detached portions being afterwards subdivided by other vertical rents at right angles to the former, have the appearance of large rough irregular columns. All the hills which I examined (in a very hasty visit) present craggy fronts to the north, and comparatively smooth and gently inclined surfaces to the south. I discovered no distinct indications of a stratified structure; but it is probable that the hills consist of a series of thick beds dipping to the south at a low angle.

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* For evidence of the removal of vast masses of rock by the action of water, see Dr Macculloch's account of the red sandstone of Sutherland, *Western Isles*, Vol. ii. p. 93; and Mr Lyell's account of the denudation of the Weald, *Principles of Geology*, Vol. iv. chap. 21.

Traprain Law, four miles east from Haddingdon, is of clinkstone porphyry, and every where exhibits the laminated structure usual in this rock. The laminæ are from half-an-inch to two inches in thickness, when viewed in large masses, but they are capable of subdivision, and in hand specimens may be seen not thicker than the tenth or twelfth part of an inch. If the bedded or stratified structure exists in the hill, as is most probable, it seems to correspond with that of the laminæ, which dip to the north-west about 40°. The height of the hill above the sea is said to be 700 feet. The south-east side of the hill is precipitous; the north-west has a comparatively moderate acclivity. The colour of the rock varies from bluish-grey to reddish-brown. All these rocks probably rest upon the lower portion of the Calciferous Sandstones.

It is now time to return to the General Section.

m, The shell or coral limestone, which is seen at intervals from Saltoun to Aberlady.

l, The trap dyke at Boglehill. It is about 150 feet in breadth, apparently vertical, and of a light-coloured fine-grained greenstone. The coal strata are seen at various points between this and Musselburgh, *h,* generally dipping to the west at a low angle.

i, The shell limestone is found under Portobello Church, marking the western boundary of the coal-field.

From Fisherrow to Granton the coal strata dip eastward. In the space from Joppa to the Maitland Bridge, about three-quarters of a mile, the dip is 50°; from Joppa to Portobello it is probably less; but if we take 30° as a mean, the distance to the Maitland Bridge being 7500 feet, the thickness of the beds will be one-half of this, or 3750 feet, and this does not include the whole of the coal measures.[*] Most part of the beach (five miles in length) from Portobello to Granton, is covered with sand; but we have indications of the position of the rocks at two intermediate points, not far from the shore. These are, the vein east of Lochend, lately open, the walls of which consisted of strata dipping eastward at 15°, and the reef called Leith Crag, at low-water mark, which consists of strata of sandstone dipping right east at 15° or 20°. At the Chain Pier the dip is to the same point, but at a very low angle. Even if we assume the mean dip from Portobello to Granton to be no more than 7½°, the thickness will be 3300 feet. Now, since the beds of black and blue shale, including some of coal, which characterise the *upper* part of the group of calciferous sandstones, are still abundant towards Granton, where the lowest visible rocks of the series ought to be found, it seems reasonable to conclude, that there are either great inflections, or, what is more probable, dislocations, between this point and Portobello, and that the effect of these dislocations has been to throw down a portion of the higher strata. Captain Boswell found two beds of coal, one of them five feet thick, on his property, right behind Granton, and at the depth of 200 feet below the sea. If no dislocation exists, these beds must be 3000 feet below the limestone, which usually forms the lower limit of the workable coal. This is extremely improbable; and therefore Lord Greenock's conjecture, that the strata at Wardie, containing the coal, have been thrown out of their original position, seems to rest on good grounds.

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[*] The thickness of the coal and mountain limestone strata from Newcastle to Cross Fell, is estimated by Mr Forster to exceed 4000 feet. He enumerates 32 beds of coal, 62 of sandstone, 17 of limestone, 1 of trap, and 128 of shale and clay. (Dr Buckland's Bridgewater Treatise, p. 64.)

It may be proper, once for all, to point out the effect of these *faults* in augmenting the apparent depth of the strata. Let us suppose a series of strata forming one bed 200 feet thick, and dipping at an angle of 20°, to be broken into three portions; the second and third, or lower portions, to be then each heaved up to the level of the first, preserving the same dip; and the projecting angles to be worn off by the agency of tides or currents, till the ends of the three portions form one continuous surface. If we walked over this surface, we would find its extent to be 1800 feet, and the apparent thickness or depth, computed at right angles to the planes of the strata, would be 600 feet, while the real thickness was no more than 200; because, instead of walking over the upturned ends of the strata once, we have walked over them three times, in consequence of three portions of the bed being thrown up in succession.* The *apparent* thickness of inclined beds, therefore, when estimated from measurements at the surface, will always exceed the *true*, if faults exist, and may even exceed it in the proportion of two or three to one. Wave-like inflections of beds may lead to similar errors. It is very probable that trap beds, which always disturb the strata less or more, may bring up successive portions of the same rocks again and again; and perhaps, on this account, a deduction should always be made from the estimated depth of formations in which numerous trap beds are interpolated.

h, The trap marked near Leith in the section, is meant for that of Hawkhill.

About Carolina Park, there are some thin beds of greenstone, intermixed with the sandstone and shale. They are light-coloured, and pass occasionally into compact felspar.

e, *f*, *g*.—A little westward of the bay at Carolina Park, a series of trap beds present themselves amidst the sandstone and shale. There are probably a dozen east of Cramond, some of them twenty feet thick; all dip N.W., or W.N.W., at various angles, from 15° to 50°. They continue through Lord Rosebery's Parks: the beds here are less numerous and less inclined, but some of them are of much greater thickness, forming at *f* the caps of hills, rising 300 or 350 feet above the sea. From Granton Bay to Queensferry the distance is fully five miles; but, measured across the planes of the strata, it will not be less than four miles, or 21,000 feet; and assuming the mean dip to be only 15°, which is certainly below the truth, the entire thickness will be 5000 feet, of which the traps may occupy 1000 or 1200.

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* Mr Landale points out examples of the deception produced by *faults* in this respect, in his valuable work. (See Report on East of Fife Coal-Field, p. 281.)

The dip changes at Queensferry, where a *fault* probably exists. A limestone, fifteen or twenty feet thick, was worked at Port Edgar, *e*, a few years ago, and is still worked, I believe, at Newton Quarry, two miles farther west. I saw no shells in it; and it is probably part of the same deposit which is found near Kirkliston, at Dechmont, and at Mid-Calder—the equivalent of the Burdiehouse limestone.

a, b, c, d.—Between Hopetoun and Kinneil the dip is generally N.W., but at a very low angle. There are four beds of trap visible on the beach, one of which, (at Blackness,) is of considerable thickness; but if the old sea-cliff which skirts the coast, and is generally covered with wood, were examined, several others would most probably be found. At Kinneil Mill, on the Avon, fully a mile back from the shore, there are one or two thick beds of traptuff.

I have placed the shell limestone, *c*, a little east of Bridgeness, though it has not, so far as I am aware, been found on any part of the coast westward of Hopetoun. That it exists somewhere here seems probable, for two reasons—first, that the beds of coal found on both sides of Earncath Hill, with a N.W. dip, are such in number and depth as to indicate that they belong to the proper Coal Measures, and of course overlie the shell limestone; and secondly, that a line connecting Hillhouse, above Linlithgow, with Charleston in Fife, at both of which this limestone is worked, would pass between Blackness and Bridgeness. It may be added, that the thinner beds of limestone, usually below the shell limestone, are found in appropriate situations. There is the limestone at Port Edgar, already mentioned; there are five beds, from four to fifteen inches thick, about half a mile west of the place called Society. There is one also, three or four feet thick, west of Borrowstoness.

ROCKS FROM EDINBURGH TO LINLITHGOW.

Before passing to the opposite shores of the Forth, it may be useful to show the influence of the trap rocks on the physiognomy of the country between the Mid-Lothian and West-Lothian coalfields. The section on the margin does not follow a straight line.

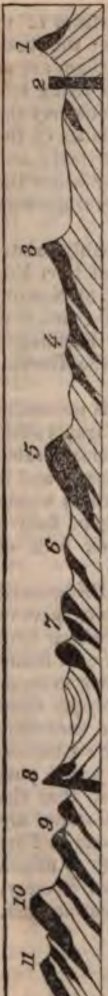


Fig. 43.

1, Arthur's Seat, the upper part of trap, resting on sandstone. Height above its base, 650 feet.
2, The Castle rock of basaltic clinkstone. Height above the New Town, 200 feet. A little westward of it, is a bed of greenstone, seen at Bell's Mills.
3, Corstorphine Hill, with a cap of greenstone 150 feet thick. It rises 300 feet above its base.
4, Various beds of trap, seen in small eminences near West-Crag Farm, and onward as far as Four-mile Hill.
5, The hills at Ratho, consisting of beds of greenstone, 200 feet thick or more. Their summit is probably 300 feet above the adjoining country.
6. Traps seen at Winchburgh and Niddry Castle, in small eminences.
7, Numerous trap hills seen about Ecclesmachen and northwards, rising from 50 to 200 feet above the Linlithgow road.
8, Binny Crag, of greenstone, rising 700 feet above the sea, and about 500 above the low country, on the Linlithgow and Bathgate roads.
9, Ricarton Hills, about the same height as Binny Crag. The shell limestone is worked in quarries between 9 and 10.
10, Cockleroy, 850 feet above the sea, and 650 above Linlithgow.
11, Bowden Hill, a little lower than the last.
12, Commencement of the Falkirk coal-field.

There are several facts worthy of notice connected with this section.

First, We find all these traps in a space of eighteen miles, and nearly on one straight line, the only deviation being at Ratho, which lies a mile southward of the section.

Secondly, Though all the traps are so placed amidst sedimentary strata, as to render it very probable that the latter at one time covered them, yet we find the traps invariably at the surface, and, except where we have reason to believe that they are very thin, we always find them capping hills. The sandstone and shale, on the other hand, are only met with in low situations; if seen much elevated, they are protected or covered by the trap.

Thirdly, As the trap-beds increase in number and thickness, the hills become higher and more numerous, and the country rises into bolder relief. On this ground I conclude, that in the low plain, covered with soil and gravel, between Edinburgh and Ratho, there are no traps except veins, or beds of small size. Had large beds existed, we should have had hills in this level tract.

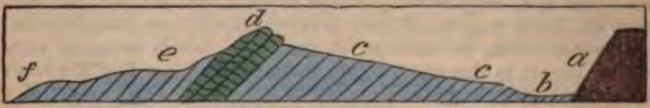
These facts prove that the country owes the present configuration of its surface to denudation, and this denudation must have been very great. We see the traps of Cockleroy and Bowden Hill rising from under the Falkirk coal-field, to the height of 800 feet. In protected situations, on the flanks of these hills, we find the sandstone at nearly an equal elevation; and if the trap beds were injected among the sandstones, as most of them certainly were, the latter must originally have been of much greater height, otherwise the liquid trap would have overflowed, and been found spreading over the ends, or outcrops, of the strata, which never, or very rarely, occurs in this district. In the same way, we find the traps of Arthur's Seat, Hawkhill, and the Calton, at the other extremity of the line, rising from under the Musselburgh coal-field. Over the intermediate space, we meet with numerous deposits of the same kind, and we always find the sandstone accompanying them to as great a height as it can find protection.

The intruding beds of trap are generally of small extent laterally. Besides those already noticed, another series extends from Cramond westward to the mouth of the Avon, keeping about a mile south of the Forth. This line is parallel to the other, only from one to two miles farther north, and includes a similar series of trap beds, the thickest of which form the summits of Earncath Hill, above Borrowstoness, and Binn's Hill, three miles farther east. Near as the two series are, the Union Canal, which runs between them, is not crossed, I believe, by more than one bed of trap between Broxburn and Linlithgow. At the latter town, it touches the traps of the southern series; but if it had followed the lowest ground, it would have reached the Avon, without cutting one of them. Of the numerous and thick beds met with between the Queensferry and the Avon mouth, very few are seen on the shore, probably not one-third.

Why the trap beds should run in bands in this way, we cannot tell; but, speaking in pure hypothesis, we might suppose that two deposits of this species of rock had existed at a great depth, in long troughs, running parallel, and that portions of it (being in a liquid state) had forced their way upward, through the seams or joinings of the strata, and thus appear as conformable beds, arranged along two parallel lines, 12 or 14 miles long, and from one to two miles asunder. These beds of trap, which are something like ribs attached to a spine, had probably, in the first place, fractured and dislocated the sedimentary strata, and afterwards served as a sort of iron framework to protect them from destruction.

That the beds under the coral limestone are of great thickness near Edinburgh, may also be shown by examining the strata westward from Braid Hill. In the bed of Braid's Burn, below Comiston, we find strata of sandstone and shale dipping N.N.W. from 30° to 50°. At the angle of the burn, where they first appear, the dip is about 50°; and it is pretty evident, from the form of the ground, that they are not more than two or three yards here from the claystone of Braid Hill, by which they have been raised into this highly inclined position. The rocks may be traced for 100 yards in the burn, and we have their continuation in Craiglockhart Hill and at Slateford. Below is a section.

FIG. 44.



a, The west end of Braid Hill, of claystone.
b, Sandstone and shale in the burn, dipping about 30° to W.N.W.
c, *c*, The straight smoothed ridge forming the tail of Craiglockhart Hill. It consists of sandstone and shale, dipping W.N.W. at 15° or 20°.
d, Beds of trap and traptuff, forming the head of Craiglockhart Hill. A small patch of sandstone, the remnant of the beds *e*, which had once covered the hill, is found at the summit. The structure of Craighouse Hill is similar, but it contains a large deposit of traptuff or breccia.*
e, Beds of sandstone dipping W.N.W. about 25° or 30°, seen in a field one-quarter of a mile north of the hill foot.
f, Beds of shale seen in the water-course at Slateford, with a N.W. dip.

Now, from *a* to *f* is precisely a mile and a half of direct distance on Knox's map, or, in round numbers, 8000 feet. If we estimate the mean dip at 15°, the entire thickness of the beds will be 2000 feet; at 20°, it will be 2600 feet. There is little doubt, too, that the beds retain this dip farther onward, though they disappear under the gravel near Slateford. At Hailes quarry, half a mile westward, the sandstone is horizontal. At Redhall quarry, scarcely a gunshot from Hailes quarry, the dip is N.W. at a considerable angle, and the stone is so entirely different, that a *fault* may be suspected to exist between the two quarries. At Colinton, near the church, there is a fine section in the water-course. The beds of sandstone and shale here dip W.N.W. at 45°, which diminishes to 15° or 20° where the river turns eastward. I have no doubt that the beds retain this position south nearly to Dreghorn.

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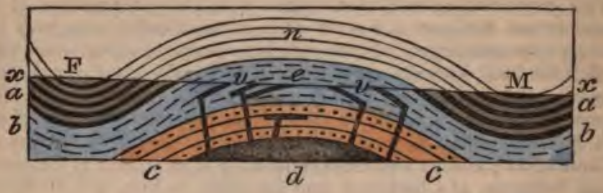
* The breccia of these hills resembles the volcanic tuffs of Salers in the Cantal; the only difference being, that the Scotch rock has undergone changes in consequence of calcareous and ferruginous infiltrations.—(Boué, p. 266.)

Amount of Denudation, and how produced.—It will be observed that the lowest strata between the Musselburgh and Falkirk coal-fields are seen at Granton on the coast, and under our city in the interior, and that they are covered by the newer on both sides. The strata whose unbroken edges now show themselves at the surface on the east and west sides of the Castle, were very probably once continuous, the intermediate portions being swept away after the beds were disrupted by trap veins and other subterranean agents, and heaved up into the positions they now occupy. The coral limestone is found at Gilmerton, Moredun, and Portobello. It is found again in the Torphichen Hills, between Bathgate and Linlithgow; and its well-marked identity of character at Gilmerton and Bathgate, at Charleston and Invertiel in Fife, and at Saltoun and other localities in East-Lothian, as well as its relations to the coal strata, leave us no room to doubt that the beds seen at these places were formed at the same epoch, and under the same circumstances, and are in fact portions of what was very probably once one great continuous whole. There is nothing startling in the amount of rock which is here supposed to have been removed; for the geology of every country teems with examples of denuding operations upon as great a scale.

In attempting to trace the nature of this change, we may suppose the rocks of the district to have presented three distinct phases in succession. First, the sedimentary rocks would be deposited in a position nearly level, and the surface would then form one continued subaqueous plain. Second, the irruption of trap at numerous localities would fissure and tilt the beds, throw up portions of them some hundred feet, and depress other portions as much. The surface would then exhibit a vast assemblage of heights and hollows, bounded by mural precipices, of which we may form an idea, by conceiving a number of bricks laid some on their sides, some on their edges or ends, with open spaces of similar magnitude between them. Third, diluvial currents would sweep away the more tender and more exposed strata, wearing down all the prominent parts, till its action was arrested by the firmer rocks, especially by beds of trap. These beds of trap, though originally injected at a considerable depth, would now occupy all the salient points of the surface, as in Figure 43, and give the country its peculiar physiognomy. It has been here assumed that the irruption of the trap beds took place simultaneously, but it must in general have occurred at different epochs. My object, however, was not so much to paint the condition of the whole surface at any one time, as to convey an idea of the sum of the changes which it has undergone from the causes referred to.

Though the intruding trap has certainly been one means of raising the stratified rocks, it is not easy to suppose that it has been the sole cause of the change which has taken place.

Fig. 45.



The above is an ideal section, on a contracted scale, of the country from Musselburgh to Falkirk, omitting *faults* and other details, for the sake of simplicity.

M, The Musselburgh coal-basin.

F, The Falkirk ditto.

x, *x*, The present surface of the country.

a, *a*, Are the coal strata, marked by heavy parallel curved lines.

n, The intermediate portions of the same strata, swept away by diluvial action: they are marked by thin lines.

b, *b*, The calciferous sandstones, lying under the coal.

e, The middle portion of this group, now swept away for the greater part.

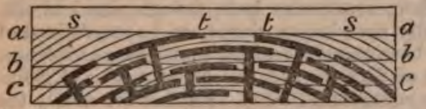
c, *c*, The old red sandstone conglomerate.

d, A rock below the old red sandstone, which we shall suppose to be a mass of trap.

v, *v*, Veins shooting up from the trap, and presenting themselves at the surface *x*, *x* in the shape of conformable beds, in the group of calciferous sandstones. These are meant to show the supposed position of the beds of traps. In so small a Figure, any attempt to represent their number would be fruitless.

We know that the Musselburgh coal strata must be from 3000 to 4000 feet in depth. Adding the calciferous sandstones, and assuming them, on the most moderate computation, to be only 2000 more, it follows that the lowest bed, which comes to the surface at Granton, must, in its eastern prolongation, be more than 5000 feet, or one mile below the upper beds at Musselburgh, M. Are we then to suppose, that beds situated like those at *v*, *v*, ejected through veins, pushed up the coal strata, and the inferior group *b*, *b*, through this vast space? That they have materially contributed to produce the effect, may be safely inferred. It is plain that a series of traps 2000 feet thick, thrown in between the beds of a group of sedimentary rocks of equal depth, must raise the thickness of the whole to 4000 feet, and of course elevate the upper sedimentary beds

2000 feet; and if the force of this elevating agent acted within a limited space, and from a focus or centre at a depth under the surface, it is evident that the elevated mass would assume a dome shape over the focus, and that the beds at its extremities would dip rapidly away from the middle, and appear to pass under the undisturbed portions of rock beyond it. This may be illustrated by the annexed diagram. The heavy black curved lines, here represent masses of trap intruded through fissures, forming veins; and the light lines *s s*, the sedimentary rocks, originally horizontal, but heaved up into a dome shape by the intrusion of the trap. If we suppose the rocks to be worn down by diluvial action to the line *a a*, two beds of trap, *t t*, will be seen at the surface. If by the farther action they are worn down to *b b*, six beds of trap and two veins will be exposed. If worn down to *c c*, the number will be still greater; and we shall have no bad representation of the district separating the Musselburgh and Falkirk coal-basin, which abounds both in trap beds and veins.



There are cases, however, where this explanation will not apply. At North Berwick, for instance, though there are many traps on both sides of what may be termed the anteclinal line there, they are intermixed with vast deposits of traptuff, which is so distinctly stratified and laminated, that it must have been deposited like the sedimentary rocks on a surface covered with water; and if the tuff was formed in this manner, we may infer that the solid trap associated with it was also laid down upon the previously existing rocks, and not injected among them. It came however, doubtless, from below; and therefore the beds which we see, if not the *cause* of the elevation, are the *sign* of the activity of the elevating agent. The tuff also may be a volcanic product; but its appearance seems to me to agree equally well with the supposition that it is a detritus resulting from the action of water on pre-existing traps. Besides, geology presents us with examples of subsidence as well as elevation; and it is by no means certain, that the depressed position of the two coal-basins may not be the result of subsidence to a certain extent.

It will be asked if we have any proofs of the Musselburgh and Falkirk coal strata having once been connected, as indicated in Figure 45? We certainly have not demonstrative evidence, but the probabilities are in favour of such an opinion. When we look to the beds, which are twenty or five-and-twenty miles apart, the assumption that they were once united, seems violent; but in reality, the data for solving the question lie in a much narrower compass. Within a space of one mile from Edinburgh Castle, westward to near Coltbridge, we have a series of strata displayed which must be nearly 2000 feet thick; and within two miles eastward from the Castle we have a similar series, in the ridge of the

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High Street, in the Calton Hill, and in the vein at Restalrig, of probably 3000 feet in depth. These strata are of the same description; they dip in opposite directions, as shown in Figure 31; and, as they every where present their *truncated* edges, it follows that they had once been more extensive than they are. But if extended even to a moderate distance upward in the same places, their ends would meet, and they would form continuous beds, though bent and disturbed, as beds frequently are where no doubt can be entertained of their continuity. We have therefore strong presumptive evidence, that strata to the depth of 2000 feet on the opposite sides of Edinburgh Castle were once connected. Now, 2000 feet are nearly the half of the whole supposed depth; and if the argument holds good as to this portion of the series, there is no good reason for rejecting it as to the rest. M. Elie de Beaumont, a very able geologist, has even adopted the opinion, that the coal deposits of the middle and north of England, of Belgium, Northern France, and Western Germany, originally constituted part of one great continued formation.[*]

It must be kept in mind that strict *identity* of strata is not contended for. According to an experienced observer, strata generally thin off and disappear laterally within a space of no great extent; but if the formation is unchanged, they are replaced by rocks belonging to the same series. I have supposed the strata removed, marked by the thin lines *n e*, in Figure 45, to have the same thickness with those which remain; but this is mere matter of conjecture. They might be of only half the depth, or less. The denudation certainly appears of startling magnitude; yet it is not unwarranted by geological analogies.

General Section, No. IV.

FROM CROMBIE POINT ALONG THE NORTH SHORES OF THE FIRTH OF FORTH TO CRAIL.

This, like the last, is a coast section, and of much the same length. The parts opposed to each other in the two sections lie pretty nearly north and south in the map, so that they afford the means of comparing the rocks on the two sides of the Firth. The cross-hatched spaces, are trap; the white, sandstone and shale: and the heavy black line marks the shell limestone. My own notes embrace the whole line comprehended in the section; but I have availed myself, for the district between Kirkcaldy and St Monance, of the more careful survey of Mr Landale, in his elaborate and valuable memoir on the Fife Coal-Field.*

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[*] "Des considerations recentes de M. Elie de Beaumont sur les relations de ces gisements houillers de la Belgique, de la France septentrionale, d'une partie de l'Angleterré, et de l'Allemagne, avec les accidents de sol, sur la distribution des fossiles, l'ont conduit à penser, qu' une grande partie de ces gisements appartenaeint à un depot continu, qui pouvait meme s'etendre encore beaucoup plus loin."—*Daubuisson et Burat, Traite de Geognosie,* Tom. ii. p. 269.

v, *w*, Thick beds of sandstone, with blackish shale in smaller proportion, and one or two beds of limestone, all dipping S.E. or E.S.E. about 15° on an average. Near Crail, the sandstone contains numerous carbonaceous impressions of the stems of trees and reeds, and coal was worked here some years ago, but is now abandoned.

u, The shell limestone, placed here by Mr Landale.

s, The St Monance and Pittenweem coal-basin, about a mile in breadth, and in which Mr Landale marks seventeen seams of coal, but either thin, or of bad quality, and not now worked. His section also exhibits five beds of limestone in the lower part of the basin, from two and a half to sixteen feet thick. The aggregate depth is thirty-seven feet. From the details he gives respecting the limestones at other parts of the Fife coal-field, it appears that there are generally three beds, but sometimes five or six, under the coal; that one or more of the beds almost always contain encrinites; and that the aggregate thickness runs from twenty feet to forty. The dip changes to N.W. at *v*, and continues to *s*, (fully two miles) at angles varying from 20° to 50°. The rocks are the same as to the eastward, but the proportion of shale greater.

r, The first trap appears at St Monance. It is a traptuff with a crumbling base; the embedded masses are not large or numerous. It extends 200 or 300 feet along the shore.

p, *q*, *r*, From *r* to *p*, (the promontory of Kincraig,) a distance of four miles in a direct line, there are at least six alternations of traptuff with sandstone and shale, and three deposits of greenstone or basalt, one or two of which, however, Mr Landale found to be veins. The dip of the sandstone and shale is reversed several times. One of the deposits of traptuff, (at a tower half a mile east of Elie,) resembles the tuff at North Berwick; but the most interesting display is at Elie harbour. The base is brown or grey, or nearly black, and contains carbonate of lime, and grains of pyrites. The included masses are of various kinds; many are of a dark basalt two or three feet in diameter, and containing grains of olivine, and crystals of augite. There are pieces of shale, fragments of limestone, masses of sandstone as large as a cottage, and blocks of older tuff two or three yards broad, inclosed in a paste of newer. The sandstone fragments are generally hard, sometimes translucent at the edges, a strong presumption in favour of the igneous origin of the rock. The appearances would lead one to suppose that the tuffaceous base was poured round the large inclosed masses. It is found filling up cavities and fissures in them, and sometimes cementing small bits of sandstone to larger ones. A film of white calcareous matter, from one-fourth to one-twentieth of an inch thick, often separates the included fragment from the base, and large veins of calcareous spar traverse the beds in different directions. The base is sometimes compact and firm, passing into wacké, sometimes coarse and feebly coherent; and in the latter case the waste occasioned by the tide leaves the hard embedded masses protuberant, and gives the surface a fantastic appearance. The tuff is found to be stratified when well exposed, and it is probably so in all cases. The washing of the sea also discloses a laminar structure, though this is seldom perceived in a fresh fracture. Besides the three beds of trap near Elie, veins of the same rock, one or two feet thick, traverse the tuff; and as they are sometimes seen projecting six or eight feet above it, are apt to be mistaken for fragments of walls at a short distance.

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* Published in the Transactions of the Highland and Agricultural Society, Vols. x. and xi.

This tuff probably belongs to the kind which has been supposed to derive its origin from eruptions of volcanic ashes or volcanic mud.*

Coal is worked behind Elie. The beds dip to the west, and are pretty numerous. (See Mr Landale's Section, No. 1.)

m, n, o, The coal strata extending to Kirkcaldy. There are numerous dykes and dislocations in this extensive tract, the places of some of which are indicated by vertical lines. Referring for details to Mr Landale's valuable memoir, I shall merely glean from it a brief account of the Kirkcaldy and Wemyss coal-field, and some particulars respecting the other parts of the district.

The Kirkcaldy and Wemyss Coal-Field.—The Coal Measures here have a general dip to the south-east, at angles varying from 1 foot in 3, to 1 in 6, averaging about 1 in 5, or 10°. They contain 29 workable seams of coal below one another, the aggregate thickness of which is 119½ feet. The individual seams vary in thickness from 2 feet to 21, but the bed of 21 feet is subdivided by thin bands of shale, and in reality consists of six beds. There is one seam only 18 inches thick, which probably would not be worth working, if it did not consist of smithy coal. Mr Landale gives sections down to the 24th seam of coal, which exhibit 157 alternations of sandstone, shale, coal, and a little clay ironstone, the entire thickness exceeding 1400 feet. If we add a proportional quantity for the other five seams, the whole thickness will be about 1700 feet, or one-third of a mile; but as the part measured is in four separate portions, probably some beds have escaped notice in the intervals. Of the 1700 feet, the coal constitutes 119½, a proportion unusually large. Taking an average of the part measured (down to the 24th bed,) we may say that there are *six* alternations of sandstone and shale for *one* of coal, and that the coal constitutes *one-fourteenth* part of the entire mass. The Wemyss coal dips south-east, passing with a moderate inclination under the sea, and is worked at the depth of 900 feet beneath its surface. Mr Landale informs us, that the ventilation is kept up by artificial means; the men breathe a good air, and are healthy and comfortable; and while immured in these " deep places of the earth," with navies riding over their heads, enjoy their joke, and laugh as merrily as reapers in a harvest-field.

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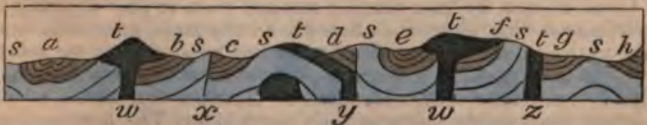
* Macculloch's System of Geology, Vol. ii. p. 116.

The northern and eastern part of the Fife coal-field is one of the most disturbed and complicated districts in Britain. In the tract of country lying betwixt the river Eden and the Forth at Pittenweem, and in the other direction, betwixt Markinch and St Andrew's, a space measuring fifteen miles each way, the trap penetrates the coal-field at innumerable places, and, according to Mr Landale's map, actually covers about one-half of the surface. The consequence of this irruption of the trap is, that the faults and dislocations, and the variations of the stratified rocks in dip and position, are beyond calculation: the great limestone, instead of being found only at the margin of the coal-field, presents itself at intervals over the whole; and the coal-field, instead of forming one extended basin, is separated into twenty or thirty detached portions, which are distributed over the district with the most capricious irregularity. The Figure below is an imaginary section, designed to convey an idea of the exceedingly disturbed and broken state of the stratified rocks, and not meant in any way to resemble those given by Mr Landale. Indeed, any attempt to compress his numerous and complicated details into such a diagram as these pages admit of, is out of the question.

FIG. 46.



The close parallel waving lines, represent the coal measures; the white spaces, the upper part of the calciferous sandstones; and the black spaces, beds, veins, or overlying masses of trap.

a, b, c, d, e, f, g, h, Small coal-basins, or rather detached fragments of what was probably one basin.

s, s, s, Portions of the inferior formation which come to the surface, and, along with

t, t, t, Masses and beds of trap, isolate the small coal-basins.

These traps are overlying masses, as at *w*, or conformable beds, as at *y*, or dykes, as at *z*. And *x* is a fault or dislocation, without the presence of trap.

It will be seen that the beds which underlie the coal, instead of being found only at the extremities of the section, have been thrown up at many intermediate points, by dykes and dislocations, and occupy a large part of the surface. I suspect the traps in the east of Fife coal-field are not so frequently overlying masses as Mr Landale thinks, but more generally beds like *y*, interposed among the sedimentary rocks. His careful examination of the district, however, entitles his opinion to much weight.

In the coal-field of Kirkcaldy and Wemyss, as already stated, Mr Landale found 29 seams of coal, having an aggregate thickness of 119½ feet; and the dip of the inner or Wemyss beds, is 10° to the east. In the Earlsferry and St Monance coal-field, taken together, he found 31 seams, having an aggregate thickness of 139 feet; and the dip of the inner, or Earlsferry beds, is 12° to the west. In the table attached to his map, however, he enumerates 34 beds in the eastern coal-field; but one is marked unknown, and one uncertain. A breadth of ten miles of sea, comprehending Largo Bay and a part of the Forth, divides these two coal-fields; and as the inner beds of each terminate at the shore, and dip towards each other, and towards the water which divides them, it seems reasonable to infer that other beds crop out under the Forth in the intervening space of ten miles. The real number of beds, therefore, perhaps reaches to or exceeds forty; and it is very probable that they meet under the water, forming a trough which is prolonged across the Forth, and re-appears in the Musselburgh coal-field. It is so represented in the map.*

The faults and dykes are extremely numerous, and have produced great changes in the elevation of the strata. They present two features worthy of notice. First, all those well ascertained have a certain degree of parallelism: they are represented on Mr Landale's map by lines running east and west, or only deviating a little from that direction. Second, all the large ones, with one exception, throw up the strata to the north; so that, as we retire inland from the Firth towards the hills, the country rises by a succession of steps or *lifts*. Mr Landale describes four faults, all of which throw *up* the strata on their north sides. The *first* running east and west between Buckhaven and Methel, throws up the coal 64 yards, cuts off 5 seams out of 16, and alters the others greatly in quality, appearance, thickness, and reciprocal distance. The great coal of 9 feet increases to 12; the others are much changed. The *second* dislocation occurs at Leven; it throws up the coal 44 yards, reduces the 11 seams to 6, diminishes the thickness of the main coal from 12 feet to 6, and the 6 and 8 feet seams to 4 and 5 feet. A *third* dislocation occurs a mile farther north, at Scoonie kirkyard: it raises the strata 200 yards, reduces the 6 seams to 4, which also lose a part of their thickness. There is a *fourth* dislocation at Largo, which throws up the strata 70 yards. The *known* upthrow in 12 miles is 388 yards, or 1164 feet; and there are other faults, whose effect, whether in raising or depressing the strata, is not ascertained. This is one-half greater than the height of Arthur's Seat. It must be kept in mind, however, that we are not speaking here of absolute elevation above the sea, but of the space through which a portion of the strata has been raised, measured at right angles to their planes. Accordingly, Mr Landale observes, that the elevation of the country, at the upper extremity of the series of *faults*, is only 200 yards above the sea.

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* See Mr Landale's Memoir, p. 293.

It seems abundantly certain, that the coal strata of Mid-Lothian are continued across the Firth, and form one series with those in Fife.* Mr Bald enumerates thirty-one workable beds in the former, having an aggregate thickness of 109 feet. In the Fife coalfield, Mr Landale describes twenty-nine workable beds on the west side, having an aggregate thickness of 119 feet, and thirty-one on the east side, with a thickness of 139 feet. As already observed, however, the Fife beds dip under the sea, at an angle which increases to 29°, within a short distance from the shore. A great number of the strata belonging to the group, therefore, must have their outcrop under the waters of the Firth, and among those we may pretty safely infer, that several additional beds of coal are included. What strengthens this conclusion is, that while the aggregate depth of the strata composing the coal measures at Kirkcaldy and Wemyss, reckoned from the coral limestone upwards, is only about 1700 feet, as exhibited in Mr Landale's tables, that of the Mid-Lothian coal measures is estimated by Mr Bald at 3000 feet. May we not therefore infer, that some hundred feet of the depth of the strata is concealed by the sea, and that these submarine beds contain a certain proportion of coal? Let us now return to the GENERAL SECTION.

m, The shell limestone dipping E.N.E. at 15°. It is worked at Invertiel, and is remarkably full of encrinites.

k, l, m, From the neighbourhood of Pettycur to *m*, we have a singular and very interesting series of trap beds. They consist of basalt, amygdaloid, greenstone, and traptuff, passing into one another, and all in beds as regular as those of the sedimentary rocks. In a space of three miles, Dr Neill enumerates sixty-five alternations.* With the traps are intermingled a few beds of sandstone, shale, clay ironstone, and about a dozen of beds of limestone, including, however, two that are above the coral limestone *m*. Some of the sandstones are much hardened, especially the thin beds. There is a stratum eight or ten inches thick very near Kinghorn, which is changed into quartz rock, and rendered as translucent as flint. The sedimentary beds lie amidst the traps without any appearance of disturbance, as if the whole had been formed in one way; and it is not surprising that the series produced a strong impression in favour of the Wernerian doctrine as to the origin of trap. The dip of the traps is E.N.E., from 20° to 35°. The series is continued westward, to a point within less than a mile of Burntisland, by five or six beds of trap; by one of traptuff identical with Binn's Hill, (probably a part of it brought down 200 feet by a fault at *k*;) and by a few beds of sandstone and shale, among which is one of a white compact flinty rock, which is probably a sandstone hardened by the contiguity of the trap. These beds are not so highly inclined as those from Pettycur eastward. The space from the lowest bed of trap at *k*, to the limestone seen on the beach at an old kiln near Abden, measured right across the beds, is fully two miles; and if we reckon the mean dip 20°, the true depth of the series, at right angles to the plane of the beds, will be 3500 feet, of which the sandstone, shale, and limestone, certainly do not constitute one-tenth part.

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* See Lord Greenock's Paper on the correspondence of the Fife and Mid-Lothian Coal-Fields, in Trans. Royal Soc. of Edin.

h, i, k, The rocks at Burntisland, dipping northward (see Fig. 37, page 82,) and towards Aberdour north-west, at 10° or 15°. In the steep wooded bank in Lord Morton's grounds (between *h* and *i*,) there are at least two beds of trap, amidst a deep series of large-grained and rather soft sandstones. These are cut off at Aberdour by a broad trap dyke *h*, which may be traced from the sea-shore to a height of 200 feet.

At the east end of Lord Morton's wood, the rivulet of Starleyburn flows down from the beds of the Newbigging limestone, and, being charged with lime, has encrusted the face of the rock for the space of 30 or 40 yards with calctuff. It takes impressions of small objects placed in it, and is known in the neighbourhood as the "petrifying" stream.

The Newbigging limestone resembles that of Burdiehouse. It is 18 feet thick, very rich, abounds in remains of plants, and has no shells visible to the naked eye, but vast numbers of the microscopic kind, called entomostraca.

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* Note appended to the Translation of Daubuisson's account of the Basalts of *Saxony*.—Edin. 1814.

g, *h*, For half a mile beyond the great dyke *h*, the strata dip eastward. Among them are four beds of trap: one of them, a greenstone 80 feet thick, forms the curved headland of Hawk Crag. There is a thin bed of trap above it; and between the two is a bed of sandstone hardened into quartz rock. There are apparently two other beds of trap at the harbour.

f, *g*, From this to Dalgetty there are four deposits of trap, which, owing to the windings of the coast-line, may be mistaken for five. The two eastern are basalt; the third, which is very thick, and forms the promontory of Braefoot, a wooded hill 200 feet in height, is of greenstone. These are divided by sandstone and shale, dipping west at 15° or 20°. The fourth is a bed of basalt, 50 feet thick, at Dalgetty, lying conformably amidst the beds of sandstone and shale.

d, *e*, *f*, From Dalgetty to St David's there are three beds of trap, chiefly greenstones I think, and one vein *e*, (at Donibristle,) 100 feet broad and 40 high, running east and west. The sedimentary rocks at Donibristle dip partly east, partly west. There is a large bed of traptuff in thick contorted strata, enclosing angular masses up to one yard in breadth, partly of limestone, partly of its own substance, but none of trap, so far as I saw. It partakes of the nature of a sandstone conglomerate, and is very different from the tuffs at Elie and North Berwick.

On the west side of St David's there is about 100 feet of blackish shale exposed, with a little sandstone, dip north-west. This is covered by greenstone, which extends a mile and a half of *direct* distance westward. Inverkeithing Bay is a crater-shaped cavity, the west and east sides of which consist of beds of greenstone, dipping inward to the centre of the bay, at an angle of 15° or 20°. The mass of trap at the North Ferry is very great, forming hills 150 feet high, and covering from one to two square miles. All which I examined was greenstone; some fine, some large-grained, some light-coloured from the abundance of felspar, forming a syenite. It very generally contains grains of pyrites.

From the most western bed of trap at *d*, to the large dyke *h*, the direct distance is about 4½ miles. Taking the average dip at 12°, and allowing for the oblique position of the beds to the line of section, the entire thickness of the series will be 3800 feet, of which probably 1700 consists of trap, and 2100 of sandstone, shale, and a tuff partaking of the nature of sandstone.

a, *b*, *c*, From the traps of the North Ferry to Crombie Point, the strata dip westward, and at a low angle. There are some exceptions, and among these one about a mile west from Rosyth, where strata of clay, ironstone, and shale, are seen dipping north at 20° to 60°. I saw only three beds of trap in this space, none of them thick. The whole thickness of these deposits, extending over four miles, may be 1800 feet, of which probably 200 is trap.

The coral limestone *b*, is worked at Charleston. It dips north-west at 10° to 15°. The visible depth of the bed is about 50 feet. It is imperfectly stratified, the strata being from half a foot to four feet deep. The colour is a bluish or light-brownish grey. It contains a good deal of carbonaceous matter, and abounds in encrinites, and shells of various sizes up to six inches in breadth. It is covered by 30 feet of slate clay.

Coal was found about one mile north of Crombie Point, but was abandoned; and the nearest seams now worked, are three or four miles to the northward of this village.

GENERAL OBSERVATIONS ON THE TRAP ROCKS.

1. *The traps in this district are characteristic of the group immediately beneath the coal measures, namely, the upper part of the calciferous sandstones.* Their number and their aggregate depth is wonderfully great. They occur sometimes within the coal measures, but only in the lowest part, and in small quantity. I speak here of beds; but, even in the shape of veins, they are scarce within the coal-fields. Traps are rare in England; but where they are found among the secondary rocks, their position is analogous. The "whin sill" in Northumberland lies under the coal, among the strata of the mountain limestone; and the toadstones of Derbyshire form there successive beds in the same limestone.*

2. *They are almost always disposed in beds, which are placed conformably among the sedimentary strata,* and hence they appear to dip towards the coal, and pass under it. The question then presents itself, Do these beds pass completely under the coal? Some English geologists think that the toadstones of Derbyshire form entire strata under the coal, (See the 2d Section in Conybeare and Phillips' work.) If the same principle were assumed here, it would follow that trap is not an upheaving agent, since in this case the coal would not be found occupying deep cavities. The probability is, however, that trap is an upheaving agent, though the elevation of particular tracts may be partly due to other causes. Next, the extreme thinness of some of the beds, and their very limited breadth in most cases, is adverse to the idea that their length can be so great as this supposition requires. Lastly, the trap beds at opposite sides of our coal-fields, do not correspond in number or species: the beds at Kinghorn, for instance, are not the counterparts of those at Elie, or on the west side of North Berwick.

3. *In the lowest part of the calciferous sandstones, where we approach the porphyries, traps of the basalt series are very rare.* In

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* See Conybeare and Phillips' Geology of England, Book iii. Sections 2, 3, and 4'

the immense mass of sandstone forming the Cairn hills, and the whole west end of the Pentlands, I have not seen a bed or even vein of trap but two; one passing near Colzium, and in a south-west direction to Crosswood, which is certainly a vein; and another on the road to Carnwath, about twenty miles from Edinburgh. The basalt of Dunsyre hill is not an exception; for the upper beds of the group certainly exist at a small distance from it on the south side. Again, in the mass of sandstone between the West Lomond hill and the Ochils, probably 1000 feet thick, I saw no traps; and Dr Macculloch has marked none in the red sandstone there, till we come to the porphyries of the Ochils. There is an apparent repulsion between these porphyries and the basalts. The red sandstone of Forfarshire, however, contains a considerable number of deposits of trap.

4. Where beds of laminated tuff are found with a base of coarser or finer detritus, either by themselves or interstratified with solid trap, the fair inference seems to be, that both have been deposited under water on the surface of pre-existing rocks, as beds of lava and ashes are laid down on the sides of a volcanic cone. Where the base of the tuff consists of wackě, as is very often the case in Fife, it is conceivable that it might be *injected among* the pre-existing rocks, as many traps have been; and even the laminated structure might be acquired in this case from the effects of pressure and gradual refrigeration. Elie de Beaumont thinks that the tuff with a base of wackě in the hill of Gergovia, is the produce of a muddy eruption, and is an intrusive rock as well as the basalt.* That many of the solid traps of this district are of later origin than the sedimentary rocks which cover them, seems obvious from two circumstances—that these rocks are altered in their texture and colour, and that they are disturbed, by the presence of the trap. On the coast between the North Ferry and Crombie Point, I found that in three instances the sandstone and shale covering the trap had undergone a change of position. They were bent down towards the trap, so as to change their western dip to an eastern one, for 100 or 200 yards. This is shown at *c*, in General Section No. IV. The others were precisely the same, though the small scale of the section did not admit of their being represented; and these are all the traps which were distinctly exposed on this portion of the coast. The nature of the change is most consistent with the idea, that the eruption of the trap in each case had been followed by a movement of subsidence, in consequence of which, the sedimentary beds next it being unsupported, bent down and assumed a sort of saddle-shape.

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* Memoires pour Servir, &c. Tom. i. p.

DEPTH OF THE COAL MEASURES.—NATURE AND ORIGIN OF COAL.

Between the Roman Camp and Gilmerton, the coal strata, as already stated, have a depth of 3000 feet according to Mr Bald's computation, and include 31 workable beds of coal. The Durham and Northumberland coal-field has a depth of 4000 feet, and comprehends 40 beds of coal; the Bristol field has 31 beds of coal, in a depth of 4400 feet. Dr Macculloch observes, that if we examine the deserted seat of an inland lake, we discover beds of compact mud, alternating with others of sand, and, intermixed with these, leaves and shells, and perhaps peat. We have here an image of the coal series.* Speaking of the lapse of time required for the deposition of this series of rocks, the same geologist remarks, that "the great tract of peat near Stirling has required 2000 years for its formation; for its registry is preserved by the Roman works below. It is but a single bed of coal: shall we multiply it by 100? We shall not exceed, far from it, did we allow 200,000 years for the production of the coal series of Newcastle, (1800 feet,) with all its rocky strata. A Scottish lake does not shoal at the rate of half a foot in a century; and that country presents a vertical depth of more than 3000 feet in the single series of the oldest sandstone. No sound geologist will accuse a computer of exceeding, if he allows 600,000 years for the production of this series alone." † The composition of the sandstone is more consistent than that of shale with rapid formation, and it may have been so produced in some instances. A bed of sandstone ten or twelve feet thick often presents the appearance of a mere concrete mass of sand, without divisions or joints other than accidental rents; and seems to differ in nothing but solidity from those deposits which a river like the Rhone may be supposed to form at its estuary, or even in a single flood. The fossil-trees found in quarries, in a nearly upright position, strengthen this inference. The one laid bare in Craigleith quarry, in November 1830, was 47 feet or more in length, and inclined at an angle probably of 20° to the strata in which it was embedded. It must, therefore, have passed through 15 or perhaps 20 feet of the sandstone. Now, wood constantly immersed in water will retain its texture and solidity a long time; but if the deposition of this sandstone had occupied a thousand years for instance, we can scarcely doubt that the upper part of the tree would have wasted away and disappeared, long before the beds of sandstone rose to such a height as to envelope and preserve it, to say nothing of the chances of floods or currents breaking it off. To give precision to this argument, however, it would be requisite to know how long wood soaked in water may exist; and this datum is yet wanting. Trees have been preserved for more than a thousand years in bogs; but the moss is supposed to have an antiseptic quality.

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* *System of Geology*, Vol. i. p. 215.

† Ibid. p. 507.

On the other hand, many sandstones which present the aspect of a homogeneous mass of sand in the quarry, without any traces of structure, are discovered by *weathering*, (that is, by the effect of air and water on their exposed surfaces for a series of years,) to be composed of regular laminæ, often as thin as paper. These laminæ, on careful examination, are seen to be owing sometimes to alternations of finer and coarser, or of looser and more compact matter; sometimes to the presence of mica, a substance consisting of minute scales like those of small fishes, and which are found not to be huddled together in confusion, but regularly laid on their sides, with their planes parallel to those of the laminæ. It is evident that this structure could only arise from the matter being deposited very gradually and tranquilly, and of course very *slowly*, as it would be in a lake not traversed by streams, or in the sea at great depths. Let us illustrate the principle by an example. Mr Horner infers, from some experiments of his own at Bonn, that the Rhine carries down to the sea annually 2,000,000 cubic yards of alluvial matter of the specific gravity of stone.[*] Let us suppose this to be spread equally over a space 20 miles broad and 30 long, in the bottom of the North Sea, near the estuary. Such a space would include an area of 600 square miles, and the sediment would compose a layer equal to half a line, or the 24th part of an inch, in thickness. Now, the Rhine has annual floods: during these it flows more rapidly, and bears down sand of a coarser quality. When the floods subside, and the speed of the water relaxes, the coarser sand will be dropped in its own bed, and only the fine mud will remain suspended till the waters reach the sea. Hence the matter deposited each year will consist of two kinds; a coarser during the four months of flood, and a finer during the eight months of low water Hence also, the layer of matter, if agglutinated into stone by pressure, or the infiltration of a cementing substance, would be composed of a film of sandstone of a coarser and a film of a finer texture, the two being 1-24th of an inch in thickness. If the area of deposition, then, is 600 square miles,[†] the alluvium of the Rhine, on this hypothesis, would form a stratum of sandstone, one inch thick, in 24 years, and that stratum would be composed of 48 laminæ, one-half of a finer and one-half of a coarser texture. A stratum one foot thick would be deposited in 288 years, and a stratum one yard thick in 864 years. The sandstone thus formed would be extremely similar to some which we find in the coal measures, and even in the old red sandstone of the English geologists. Periodical changes, such as the floods of rivers produce, afford an intelligible explanation of this structure. In extensive deposits, the alternations probably correspond to annual changes; but in small deposits near the shore, they may be as numerous as the transient floods in the streams which produce them.

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[*] Edinburgh Philosophical Journal, January 1835. The precise number arising from his calculation is 1,973,433 cubic yards.

[†] The space is assumed merely for the sake of illustration. In point of fact, the alluvium of the Rhine has supplied the greater part of the materials of the numerous sand-banks of the North Sea, and must be spread by the action of the tides over twenty or thirty thousand square miles.

Much of what has been said applies equally to shale or slate clay, in which the schistose structure is often extremely fine and regular. It evidently consists of clay or mud, which has been suspended in water, and deposited very slowly. This is farther attested by the plants embedded in it, in which the delicate foliage often appears as if spread out carefully by the hand, without any marks of being crushed or bruised. "Indurated clay," on the other hand, seems a hasty deposit, for it scarcely presents any traces of a definite structure.

Limestone containing shells and corals presents clear evidence of being slowly formed. All the shells must have been the growth of a certain period of time; some of the larger ones probably of 20 or 30 years. Now, there are beds several yards in thickness, almost entirely composed of these *exuviæ* of marine animals, each of which must have lived long on the surface of the stratum of which it now forms a part. It is probably no exaggeration to say, that there are laminæ of limestone one inch thick, each of which must be the product of one or two centuries. Let it be farther observed, that there is seldom any thing in the composition of the beds in which shells are wanting, to indicate with certainty that they were more rapidly formed than the beds in which they exist.

Coal affords evidence of a different kind, but equally conclusive, of the long lapse of time required for the production of the rocky strata. But its nature and origin must first be adverted to.

Nature and Origin of Coal.—It is now universally allowed that coal is the product of decomposed vegetable matter; and there are two hypotheses as to the mode in which it was brought together in such vast quantities. Deluc, Brongniart, Dr Macculloch, and Mr Hutton of Newcastle, think that the plants generally grew and died on the spot where the coal exists, and that a bed of coal was analogous in its origin to a peat-bog. The other hypothesis (which is perhaps more generally received) assumes that the vegetable matter was swept from the land into estuaries or lakes by inundations and streams, as the trunks and branches of trees, with plants and foliage, are carried down by the Mississippi and St Lawrence in North America.* The difficulty of accounting for the immense accumulations of vegetable matter spread over such extensive areas, is great in either way. But without going into the comparative merits of the two hypotheses, the former is assumed as true, for the purpose of illustration, in the following remarks:—

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* See Phillips' Geology, p. 176, in Lardner's Cyclopædia.

Coal was analogous in its origin to modern peat, and each bed was most probably formed on an extended surface of marshy land, covered with a rank vegetation. The finest caking coal, Mr Hutton considers as a crystalline compound, whose constituents had been in a state of solution; but slate coal and cannel coal often bear distinct impressions of plants. The new method of cutting minerals into slices so thin as to be transparent, of which Mr Witham has made so happy a use, has been applied to coal; and by examining these with the microscope, the vegetable structure has been detected where no external trace of it was visible. In cannel coal it exists throughout the whole mass, while the fine coal retains it only in small patches, which appear as it were mechanically entangled. Among other indications of the ligneous origin, tubes have been discovered filled with a yellowish resinous matter, which is the most volatile part of the coal, being what is first driven off by heat.* All coal, therefore, had originally existed in the state of plants or trees. About three hundred species have been found in the sandstone and shale of the coal measures; and the greater part of these probably exist in the coal itself, though the tenderness and opaqueness of the material render it difficult to detect them by examination. The three hundred species are all extinct. About two-thirds of them are ferns; the others consist of large Coniferæ (allied to the pine,) of gigantic Lycapodiaceæ, of species analogous to the Cacteæ and Euphorbiaceæ, and of palms.† The plants indicate a moist climate, as hot as that of the tropics; and this holds true in the coal plants, not only in England, but at Melville Island within the polar circle. Dr Hutton thought that the vegetables had been carbonized by heat;‡ but Dr Macculloch contends, on good grounds, that the change has been effected solely by water and pressure, and that by these agents peat is capable of conversion into coal.§

In the coal, therefore, familiarly used in our houses, we have the forests of primeval times, deprived of their watery and volatile parts, but preserving all their combustible matter, laid up for our use, as it were in vast cellars under our feet, closely packed, and protected from air, rain, and floods, by a solid covering of rock and soil. Few of those who are in the daily enjoyment of the comforts and advantages derived from abundant supplies of this fuel, think of the long and operose processes by which it was prepared in the laboratory of nature. A short calculation will explain what is here meant. Wood affords in general about 20 per cent. and coal about 80 per cent. of charcoal.* Neglecting the oxygen and hydrogen, therefore, it must have required four tons of wood to yield the charcoal which we find in one ton of coal. Let us then suppose a forest composed of trees 80 feet high, that the trunk of each tree contains eighty cubic feet, and the branches forty, making 120; the weight of such a tree, at 700 sp. gr. will be two and a quarter tons; and allowing 130 trees to an acre, we have 300 tons on that space. Supposing the portion that falls annually, leaves and wood, to be equal to one-thirtieth, we have ten tons of wood annually from an acre, which yields two tons of charcoal; and this charcoal, with the addition of bitumen, forms two and a half tons of coal. Now, a cubic yard of coal weighs almost exactly one ton; and a bed of coal one acre in extent, and three feet thick, will contain 4840 tons. It follows, therefore, that one acre of coal is equal to the produce of 1940 acres (that is 4840 divided by two and a half) of forest; or if the wood all grew on the spot where its remains exist, the coal bed three feet thick, and one acre in extent, must be the growth of 1940 years! Even if we suppose the vegetation, as that of a tropical climate, to be twice as rapid as I have assumed, we shall still require about a thousand years to form a bed of coal one yard thick; and for the thirty-six yards of coal in the Mid-Lothian field a period of 36,000 years! When we reflect farther that the coal constitutes only one-thirtieth part of the entire series of beds comprehended in the group, some of which were probably formed by as slow a process, we shall have no reason to reject Dr Macculloch's estimate of 600,000 years as too long for the production of the whole mass.

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* Lindley and Hutton's Fossil Flora.—Preface to vol. ii. pp. 17—26.

† Mr Delabeche enumerates 310 species of plants, twenty-eight species of shells, and three of fishes.—*Manual*, p. 390. Professor Lindley has shown that these fossil plants cannot be considered as a fair representation of the Flora of that period. As the conversion of plants into coal took place in lakes or estuaries, those plants which long resist decomposition in water have their forms preserved; those which decay rapidly, had passed into a state of solution, or exhaled in a gaseous form, and disappeared.—*Fossil Flora, No.* 17.

‡ Playfair's Illustrations of the Huttonian Theory, Note 2.

§ Paper on Peat, in Professor Jameson's Journal, 1820, Vol. ii. See also Conybeare and Phillips' Geology of England and Wales, p. 331.

An attempt to explain the formation of the coal strata leads us to infer many changes of level in the land or water, and is attended with considerable difficulties. The sandstone, shale, and limestone, must all have been formed under water, and the coal on land, perhaps in a marsh. In the section of the Mid-Lothian field, for instance, the coral limestone at the bottom must have been formed in the sea. We may then suppose the bottom to have been raised by the deposition of four fathoms of sandstone and shale, formed of detritus swept down from the neighbouring land, till the gulf or bay shoaled into a tract of marshy ground. Upon this forests grew for a thousand years, the spoils of which accumulated where they fell, and formed a thick stratum of vegetable matter. The land must then have sunk suddenly or gradually under water to a great depth, and remained there perhaps for ten thousand years, till a fresh deposit of sandstone and shale, to the depth of nineteen and a half fathoms took place, the pressure of which, aided by water, converted the stratum of wood into coal, No. 1. By this deposit the bottom was raised, the bay again converted into marsh or meadow, upon which vegetation again flourished for a thousand years, till the materials of a second bed of coal (No. 2.) three feet nine inches thick were collected. A third submergence took place, nineteen fathoms of rocky strata were deposited, the water again shoaled into land capable of bearing plants; a third period of forests commenced, and continued till the mass of vegetable matter destined to form the bed of coal No. 3, six feet thick, was accumulated. This was followed by a fourth subsidence, during which six fathoms of strata were deposited. The land, by this addition, again rose above water, was clothed with wood, and materials for a fourth bed of coal were accumulated. I need not pursue the series of changes farther. The land must have subsided more than thirty times, and descended through a space of 3000 feet, from the formation of the coral limestone to that of the uppermost beds of the group; and after these subsidences were completed, a series of counter movements, resulting partly from the agency of trap, must have again elevated a great portion of the beds above water. Such numerous changes when surveyed in the aggregate, and without reference to time, appear inconsistent with the usual stability of nature; but the inconsistency vanishes on a little reflection. The changes now produced by earthquakes, and the faults and fractures of the coal strata, assure us beyond all doubt that rocky masses have undergone movements both of subsidence and elevation; and as to their great number or apparent frequency in this instance, when we consider them as diffused over a period of half a million or a million of years, it is obvious at once that the objection loses its force.

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* See Analysis of various species of coal.—*Daubuisson et Burat*, ii. p. 281.

It is inferred that the water under which the sandstone and shale were deposited, was chiefly that of lakes; for five-sixths of the plants, according to Adolphe Brongniart, are such as grow on land or in fresh water. Of the tribe of Algæ, comprehending seaweeds, he found none.* The scales and teeth, however, of the great predaceous fishes formerly mentioned, (page 79,) and the shells of genera allied to the mussel and oyster, indicate that salt or brackish water was occasionally present.

The repeated subsidences, so many in number, form one objection (and there are others) to this hypothesis; and yet, if the coral limestone exists, as we have every reason to believe, under the Newcastle and Durham coal-fields, at the depth of 2000 feet or more beneath the sea, the fact of subsidence to this extent is proved; for it is now admitted that all corals were formed at or near the surface of the ocean. Whether this subsidence took place at once, or by successive stages, is immaterial.

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* Aucune empreinte qu'on puisse rapporter avec quelque certitude, à la famille des Algues n'a eté decouverte dans ces terrains.—*Prodrome d'une Histoire des Vegetaux Fossiles.* P. 167.

The other hypothesis is thus explained by Professor Phillips, with reference to the coal formation of Yorkshire. The alternating beds he attributes to alternating currents from different points of the compass, charged with different sediments, and passing into a great estuary or lake. Lime, he thinks, was transported by the marine currents from the south-east, because the limestone beds are thickest in that direction, and thin off towards the opposite point: argillaceous sediment was swept in by a river from the west, the shales being thickest in that direction; while sand and floating wood were drifted from the north, the beds of coal and sandstone being thickest in that direction. This hypothesis, like the other, involves various difficulties, of which two may be mentioned. Of the four currents bearing wood, sand, clay, and lime, how did it happen that three so generally suspended their action, while the fourth was operating? Again, supposing the wood to be floated from the north by a river which inundated its banks like the Mississippi, it is plain that such a stream could carry off only a small part, probably not one-thirtieth, of the spoils of the forest annually deposited in its hydrographical basin. It follows, that to furnish materials for a bed of coal extending over a given space, the river must have drawn its waters from an area thirty times as large as would be required if the wood was carbonized where it grew, or the period must have been thirty times as long. But, looking to the extent (once much greater than it now is) of the coal formations in the north of England and Scotland, where is the continent to be found in which such a river could exist? Mr Phillips, in fact, finds it necessary to admit, that the large tracts of land required to furnish the sediments of sand and clay, and the masses of vegetable matter, have disappeared in the northern and western oceans.[*]

The fossils of the coal measures are chiefly plants. They are most abundant in the shale, but are also found in the sandstone. They generally lie on their sides; but various examples have been found of trees standing erect, piercing through several beds, with their roots spread out, and so circumstanced as to lead to the conclusion, that they have been converted into stone at the very spot where they grew. Fossil trees seldom exceed a few feet in length; but examples are cited of some 20 feet long, found in what is considered their native locality. Their roots are sometimes in sandstone, but more frequently in a bed of shale, which had originally consisted of fine mud, and formed the soil in which they grew. Trees which had been transported from their native seat, are, however, infinitely more common, and these have been found of great length. A magnificent specimen was exposed in Craigleith quarry

[*] *Treatise on Geology*, Pp. 177—180, Lardner's Cyclopædia, 1838.

in 1833. Its colour approaches black; it is about three feet in diameter; and there were above twenty feet of its length exposed when I saw it in 1834. It has no branches, but the scars where branches had been inserted, are well marked. It has been ascertained by slicing to be a Conifera of the genus Araucaria, of which living species exist in New Holland. Like its modern type, the fossil tree wants those concentric rings which mark the annual additions made to the growth of pines. It was analyzed by Mr R. Walker, and its constituents were found to be carbonate of lime, 50.36; carbonate of iron, 24.65; carbonate of magnesia, 17.71; coal with silica and water, 6.15.* It penetrates the sandstone obliquely, at an angle perhaps of 20°.

Structure of Fossil Plants.—The ingenious method lately discovered of cutting stones of all kinds into transparent slices, promises to conduct us to a much more perfect knowledge than we now possess of the structure of fossil plants, and, in fact, to reveal to us the true character of the Flora of the ancient globe. Mr Witham's book "On the Internal Structure of Fossil Vegetables," published in 1831, first made the public fully acquainted with the important source of information which this curious art opens up. I shall borrow one or two illustrations from his second edition (1833,) premising a few observations on the physiology of plants.

The matter which forms the stems, branches, roots, bark, leaves, fruits, and flowers of plants, however various its appearance, consists essentially of only two substances, vascular bodies or vessels, and cellular tissue. The vascular bodies (which we shall call simply vasculars) are *pipes or tubes* appearing like fibres to the naked eye, many of them smaller than the finest hair, but which are discovered by the microscope to be hollow. They run from the root of the tree to its remotest branches and leaves, and convey the sap from the earth through all the parts of the plant. It has been found that 2500 of them placed in a line can stand in a linear inch, and 7,000,000 in a square inch. They form only a part of the plant, and (taking the trunk of a tree as an example) are surrounded on all sides by the other substance called CELLULAR TISSUE. This consists of *cells or bladders*, from the size of a fine pore to that of a small pea. Their primary form may be considered as globular, or sometimes oblong like a sausage, but by mutual pressure they assume the form of six-sided prisms, and on a small scale resemble the cells of bees. Their sides consists of a membrane thinner than fine paper. Though apparently close on all sides, they are sometimes found filled with a liquid, which they are supposed to receive from the sap-vessels (vasculars,) and to elaborate into matter for the nourishment and growth of the plant. They are also frequently found empty; and, in this state, may be seen with the naked eye in the *pith* of some shrubs and trees. The cellular tissue is called "parenchyma" by some writers.

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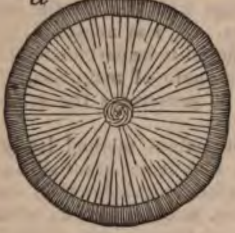
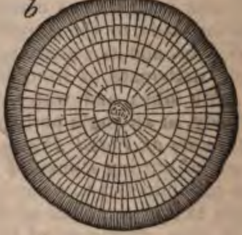
* Edinburgh Philosophical Journal, for January 1834, and April 1835.

These two substances separately, or variously mixed, compose the pith, wood, bark, roots, leaves, &c., of plants.

a



b



In the common *ash* tree, Fig. *a* above, the vasculars are not arranged in isolated groups, as in the cane, but in radii or "rays," shooting out on all sides from the pith to the bark, with partitions of cellular tissue between them. On the outside of the wood, is the bark or "cortical texture," consisting of vasculars and cells, but mixed in different proportions, and not in "rays." The radiated structure belongs to all the firm and useful varieties of wood, we believe, without exception. There are, besides, subordinate peculiarities of intimate structure, depending on the size, distribution, form, &c., of the cells and vasculars, by which one kind of wood can be distinguished from another, such as oak from ash, &c.; and among these are certain large tubular vessels—sometimes with spiral walls, such as would be formed by coiling a cord or ribbon round a ruler. There is yet another marked peculiarity. In trees that grow in cold countries, and are exposed to great annual changes of temperature, the winter produces a contraction of the vessels and cells all round the exterior; and transverse slices of such trees, when examined, exhibit *circular rings*, marking the annual layers of wood, and placed one without another from the pith to the bark, Fig. *b*. This appearance, which is known to every one, makes a tree a sort of natural calendar: the successive rings not only tell its age, but by the variation in their breadth, informs us, whether particular seasons were favourable to vegetation or the reverse. In the wood of tropical countries, these rings are either very faint or altogether wanting, Fig. *b*.

Speaking comprehensively, we may say that herbaceous plants are sometimes entirely composed of cellular tissue; in other cases, they have much of it in the shape of pith, and a little "woody texture." Canes and palms have no proper pith, no radii or annual rings, but strings or fasciculi of vasculars, irregularly distributed lengthwise through the cellular tissue. Timber trees in warm countries have pith in the middle, surrounded by radiated "woody texture," Fig. *a*. Trees in cold countries have pith in the middle, and radiated woody texture in common with those of warm regions, but they have in addition circular rings, Fig. *b*. Longitudinal slices, or sections of the plant lengthwise, are equally characteristic with transverse ones; but I have not room to speak of these.

Plants are divided into three classes, according to the structure of their seeds. Those without flowers or seed-lobes (acotyledonous) have no veins in their leaves, and no woody texture; plants with flowers and one seed-lobe (monocotyledonous) have the veins of their leaves running parallel or nearly so to the midrib, have no distinction between the pith and wood and bark, and no radiations. Plants with flowers and two seed-lobes (dicotyledonous) are the most perfect; the pith, wood, and bark are distinct; the wood is radiated; the veins of the leaves diverge from the midrib, and are branched.

Hitherto geologists have attempted to classify fossil plants by their external form and appearance. This was disadvantageous; because sometimes the external parts (the bark, for instance,) were wanting, or accidental injuries might be mistaken for natural characters; and even though existing in the fossil, and well marked, they give, in many cases, equivocal indications as to the true nature and habits of the plant. But the method of slicing, which has recently been introduced with the happiest success, conducts us into the interior of the plant, and reveals the most intimate peculiarities of its structure. It was once thought wonderful that the imbrications and delicate markings of the exterior of a tree, should be so well preserved in stone; but how much more marvellous is it, to find the forms of minute vessels and cells not the thousand part of an inch in diameter, with the details of the curious and complicated textures which they constitute, preserved in the same rough material, with all the accuracy and distinctness which they possessed in the living plant? This is beautifully exhibited in the specimens prepared for Mr Witham by Mr Sanderson. That ingenious lapidary saws a slice of the fossil plant, polishes one side of it smooth, attaches it to a bit of plate glass by Canada balsam, and holding it to the wheel by the aid of the glass, grinds down the outer side till the slice is as thin as fine paper, and then polishes it. It is now transparent, and being placed in the focus of a microscope, and exposed to a strong light transmitted from below, its minute structure can be surveyed at leisure. The subjoined figures, copied from plates in the work, will exemplify the appearance of the slices, and give the reader some idea of the nature of the data on which Mr Witham proceeds, and the value of the inferences derived from them.

Fig. 47.

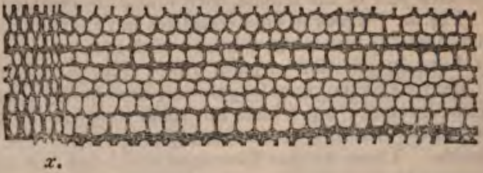


Fig. 48.

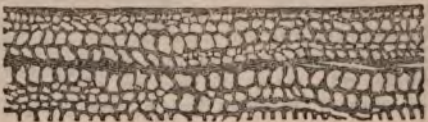


Fig. 47, is a transverse section of the ***Pinus Sylvestris***, or Scotch fir, taken from a living tree, and magnified 100 diameters. The cells of the cellular tissue will be seen to be of a hexagonal, or a six-sided shape; there are about ten of them in the length of an inch, but as the magnifying power employed is 100, the real number must be a thousand, and in a square inch a million. The darkish broad line extending from right to left at the bottom, is a "medullary ray," or one of the radii proceeding from the pith, or *medulla*, in the centre, to the bark. These "rays" consist, in part at least, of very minute vasculars, or sap-vessels. The dark part *x*, at the end, is the condensation produced by the winter's cold, and marks, of course, the boundary of one of the annual rings.

Fig 48, is a transverse slice of the fossil-tree found in Craigleith quarry in 1826, also magnified 100 times. It will be seen at a glance how correctly it corresponds in structure with the living fir. There are cells of similar form and size; "rays" of exactly similar appearance; and irregular thickenings of the walls of the cells at parts between the rays, as in the living tree. One thing alone is wanting; there is no trace in this, or other specimens of the same fossil which Mr Witham examined, of the *annual rings*, indicated by the condensed part *x*, in Fig. 1. The fossil tree of 1830, and the branch of 1831, found in the same quarry, are equally destitute of any distinct traces of the annual rings. It is hence inferred, that when these trees grew in this part of the globe, our climate was not distinguished by the alternations of summer heat and winter cold which it now exhibits, but possessed the equability known at present only within the tropics.

Mr Witham has examined many scores of these fossil specimens, and all those taken from the coal formation agree in this peculi*arity of wanting* the annual rings. They also all belong, we think, to the class of *coniferæ* (a subdivision of dicotyledons,) and are, therefore, of the same tribe with the pine; but they differ considerably from one another. Judging from these facts, the vegetation of this region at the period in question, had been very little diversified.

Mr Witham also examined a number of fossil plants from the Lias formation, which is a good deal more recent than the coal. In one of these, from the Island of Eig, and in several of the others, he found decided marks of the annual rings, indicating alternations of temperature, such as we now experience. In specimens of fossil wood from Antigua, he detected organic structures corresponding closely to those of various other living trees and shrubs, namely, oak, mahogany, sandal-wood, sugar-cane, &c.

In the upper formations generally, he found the fossilizing substance (the stony matter which had replaced the plant) to be generally lime, frequently mixed with oxides of iron; and a considerable portion of carbon is always present, either in the simple state, or forming a carbonate with the lime. In the coal formation, the fossilizing substance was generally siliceous. The perfect preservation of the organic structure, shows that the process had been slow. We may conjecture, that water holding lime or silica in solution, had rested long over the sand in which the trees were imbedded. The interior of the vessels and cells would be filled first with the dissolved matter; then their walls would be slowly replaced by the same substance, the carbon either retaining its place, or forming carbonic acid, and uniting with the lime. There can be no doubt, that the same process is going on along our shores, and at the estuaries of our rivers at the present day.

Structure of Fossil Bones.—The ingenious analysis of the bones and scales of fossil fish by Mr Connell, illustrate the process by which the lapidification is effected. He found that the phosphate and carbonate of lime remained almost unaltered, and formed, as it were, the framework of these bodies; but the purely animal matter filling cells or cavities in this framework, had disappeared, while its place was supplied by groups of minute cylinders or layers of a siliceous substance, which had passed in by infiltration, and filled up the vacuities. On comparing the bones of a recent pike with the bony rays of the gyracanthus from Burdiehouse quarry, we have merely to substitute 38 parts in the 100 of silica in the latter, for 38 of animal matter in the former, to make the analysis agree to a fraction.*

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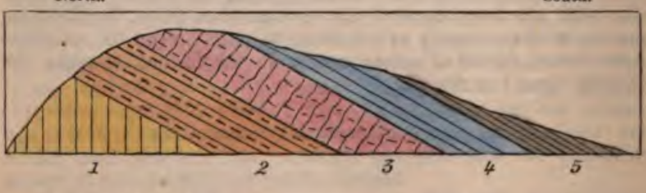
* Edinburgh Philosophical Transactions, 1834.

PENTLAND HILLS.

THE length of these hills is about sixteen miles, and their extreme breadth six. The height of the summits varies from 1400 to nearly 1900 feet. That of Carnethy was ascertained by levelling by Mr Jardine, and found to be 1877 feet. South Black Hill, the most elevated of the whole, is sixteen feet higher. East Cairn Hill, according to the table in Knox's map, is 1802 feet; West Kipps Hill, 1786 feet; West Cairn Hill, 1764 feet; Allermuir Hill, 1606 feet. These are the most elevated points of the chain. The general height of the hills above their base, is from 1000 to 1300 feet. The direction of the axis of the chain is almost correctly N.E. and S.W. The eastern part of the hills forms a single massive group for two miles: beyond this, for the space of six miles, they divide, and form two parallel chains, whose summits are about a mile asunder: the western part consists of a large uneven circular plateau, about five or six miles in diameter, with a southern inclination, and from 1200 to 1400 feet in height, forming the upper basin of Lyne Water. All the considerable streams rise near the north-western side of the hills, and flow south-eastward. The steepest acclivities front the north; and the hills have generally rounded summits, covered with heath or grass; but there are also some bare escapements of rock.

In a general point of view, the Pentland hills, at the west end, consist of sandstone; in the middle, of greywacké and clayslate, in vertical strata, covered by overlying conglomerate; and at the east end, of vast masses of porphyry. Where all the rocks are found in connexion, they present themselves in the following order, beginning with the lowest.

FIG. 49.



1, Clayslate and greywacké, in vertical strata.
2, Conglomerate, in overlying beds.

3, Porphyries, with base of felspar, clinkstone, and claystone. In one instance, the porphyry is found reposing immediately on the clay slate.
4, Calciferous sandstones.
5, Coal measures.

This sketch of the general structure of the hills, will render the description of the sections more intelligible.

The most conspicuous rocks of Pentland hills, and those which chiefly determine their form, are the overlying beds of porphyry and conglomerate. The direction of these, from Carlops eastward, is N.E. and S.W., corresponding with the axis of the chain, and the dip S.E. From Carlops westward, in the district watered by the Lyne and its branches, the direction of the beds is irregular, but, generally speaking, E. and W., the dip S. This does not apply, however, to the sandstone hills; for these curve round the north-west end of the chain, having their dip N.W. and W. and S.W.

To exhibit the position of the rocks properly, it is necessary to make sections at right angles, or nearly so, to the direction of the beds; and most of the sections now to be described are constructed on this principle. It may be proper also again to repeat, that as our means of observing the rocks are limited, by so much of the surface being covered with grass, heath, clay, or gravel, it must not be supposed that the beds and strata described can be seen at every point along the line traced on the map. On the contrary, many of them are to be found only at some distance to the right or left; and their existence along the line of section is merely inferred. Nor is it to be understood, that if nature had laid bare the interior structure of the hill along that line, every bed would be found where it has been placed in the sections, or that no others than those indicated would be found there. Many of the beds, both igneous and sedimentary, are limited and local; and their appearance at one spot is no security for finding them at another a few hundred yards distant, where their position would lead us to infer their existence. Such sections must generally embody errors both of omission and redundancy, and are to be received merely as approximations to the truth, more or less correct according to the number and accuracy of the data on which they rest.

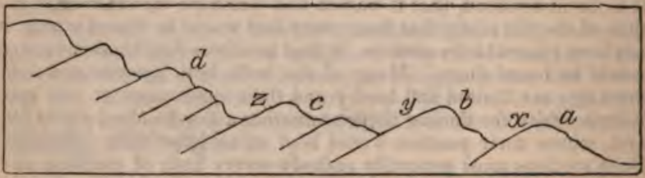
SECTION, No. V.

THE line of this section runs N.W. and S.E. across the end of the chain: its length is about three miles; Kirkyetton Crag, the highest point of it, is 1580 feet above the sea, and probably about 1150 above its northern base at Dreghorn village. The line is marked V.Y in the map.

From the south-east end of the section to Dreghorn village, the rocks consist of a series of porphyries, with bases of felspar, clinkstone, and claystone. In some cases the porphyry becomes an amygdaloid, and contains rounded or oblong cavities, filled with green earth, quartz, and agates, from the size of a pin-head to that of an apple. Sometimes the agates and other embedded substances present themselves in fine threads, or small veins, of various sizes up to the breadth of a quill or larger. These rocks belong to the *quartziferous* or *agathiferous porphyry* described by geologists, and generally found associated with the oldest secondary rocks, especially the *old red sandstone*, to which group the sedimentary deposits of the Pentland hills are chiefly referrible.*

These igneous rocks generally exhibit an appearance of subdivision into beds, and dip to the south-east, at angles varying from 20° to 45°, and perhaps averaging about 30°. The surface exposed along the line of section to Dreghorn is about two miles in breadth, and the aggregate thickness of the beds must be nearly one-half of this, or from 4000 to 5000 feet. The igneous rocks, however, probably extend farther in both directions, though concealed by the soil. The different species pass into each other, and in their transitions exhibit a great variety of aspect. The bedded structure is often very obscure, but its existence can scarcely be doubted by one who makes an extensive examination of the hills. Let any one, for instance, ascend in a south-easterly direction from the foot of the hills midway between Dreghorn and Swanston, to the top of Kirkyetton hill: he will pass over a series of projecting crags of this form:

Fig. 50.



At *a*, *b*, *c*, *d*, he will find escarpments of bare rock exposed, fronting the north-west, and occasionally subdivided by seams so as to represent the edges of strata. At *x*, *y*, *z*, on the other hand, he will find himself on smooth grassy surfaces, dipping south-east at a considerable angle, and visibly forming the upper planes of beds. The rivulet between Swanston and Dreghorn, called Hare Burn, flows in one of the deepest and best marked of these cavities. Over the whole space between Dreghorn Burn and Swanston Burn, abrupt projections, like *a*, *b*, *c*, are met with, and always in corresponding positions. We find them also extremely well marked at the eastern extremity of the hills, where the rivulets of Bowbridge and Lothian Burn flow in depressions precisely similar to that of Hare Burn, but on a larger scale. If we pass again to the south side of Allermuir and Kirkyetton hills, we find a steep but remarkably smooth surface, with a south-easterly inclination, and scarcely broken by a single protuberance. The same appearances are generally seen to the westward. In Warklaw hill the successive beds crop out beneath one another in a manner too distinct to admit of any doubt, (See General Section, No. VI. ;) and in South Black Hill and Broad Law, the south-east dip of the beds of claystone and felspar, which crown these hills, is also well marked. To all this must be added, that the variety in the character of the rocks can only be seen by crossing the northern front of the hills, in the direction referred to in the diagram, namely, from the N.W. to S.E., which proves that this line runs transversely over the upper edges, or outcrop of the beds. In the outline of the General Section, No. V., an attempt is made to mark this peculiarity. The joinings of the beds, however, are scarcely ever visible ; and the divisions in the section must not be understood to indicate either their true number or their relative thickness. For such details it is scarcely possible to obtain data. Again, we find some of the beds of porphyry subdivided by fissures into strata, or tabular portions parallel to each other and to the base on which the bed rests. I have gone into these explanatory statements, because the indications of the bedded structure are obscure in many parts of the hills ; and, in common parlance, the term of " unstratified" is often applied to the traps of all ages, though stratified porphyries are not uncommon either in the old or new continent.*

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* See Humboldt "On the Superposition of Rocks," from page 213 to 254; English *translation.*

The section gives a general view of the nature of the beds, but a few additional details are necessary.

The first and most easterly bed of the hill, seen a little southward of Hillend farm-house, is a fine-grained dark reddish-brown clinkstone porphyry, which at some parts becomes compact. West of this is an amygdaloid *b*, of a striking aspect. The base seems to consist of the red porphyry just mentioned. The cavities are chiefly of a roundish form, and of all sizes up to an inch in diameter ; the smaller are generally filled with green earth ; the larger with agates, calcedony, calcspar, heavy spar, and quartz, but a coating of green earth usually separates the matrix from the included nodule ; and the vast number of cavities so filled, gives the rock a greenish aspect. This is succeeded by a red porphyry, like the first, which assumes various aspects ; sometimes it is of a fine texture, of a deep brown colour, and nearly compact ; again, it contains small grains or thin crystals of white felspar irregularly disseminated ; or it assumes the character of an amygdaloid, presenting along with agates opaque nodules of a deep red colour, like embedded fragments, but separated from the base by a film of white spar; or a fine and uniform mixture of the red and white matter, gives it the aspect of a brownish greenstone. This rock forms the steep eastern declivity of Kirkyetton Hill. Next we have a large bed of compact felspar, *c*, forming the northern escarpment of Kirkyetton Hill. It passes sometimes into claystone, sometimes into hornstone. It is of a yellowish or reddish-white colour, which is occasionally variegated by iron-shot spots of red. Close to this, on the west, is a dark red porphyry, *d*, which weathers so deeply, that it moulders down on receiving a slight blow, and a fresh specimen is not easily procured. It contains numerous small white crystals of felspar, which are well defined, and nodules and veins of agate and calcedony.* It differs from *b*, in containing very little green earth, and in the greater looseness of its texture. This well-characterised rock is found at various places as far as Kipps Hill, about five miles to the westward, and in an analogous position, accompanying and covered by a white felspar or claystone. These red porphyries compose the largest mass of the hills along this line of the section. The base is sometimes felspar, sometimes clinkstone, sometimes claystone.

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* See Humboldt on the Porphyries of Mexico and Hungary.—(" Superposition of Rocks," Pp. 219, 245.)

The felspar of the Pentlands is flesh-red or brownish-red, sometimes greyish and yellowish white, and ash grey and yellowish grey. It is massive. The lustre is glimmering, and the fracture minutely foliated and splintery, and sometimes conchoidal, sometimes slaty. It is semi-hard and brittle. Specific gravity, 2,497. The clinkstone when pure is a deep greenish-grey colour, but when iron-shot, which is generally the case, it is reddish-brown; the lustre of the principal fracture is glistening, of the cross fracture glimmering. The principal fracture is slaty, the cross fracture uneven, passing into uneven and small conchoidal. It is translucent on the edges, hard, brittle, rather easily frangible, and rather heavy. It is nearly allied to felspar, and is to be observed passing into compact felspar. The claystone has its principal colours grey, blue, and red; and it frequently exhibits dendritic delineations. Its fracture is earthy and dull. It is opaque, soft, rather brittle; rather easily frangible; feels meagre and tough; does not adhere to the tongue; rather heavy. It is stratified, and passes into compact felspar.†

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* The crystals inclosed in porphyries were formed while the rock was in the process of consolidation. The crystalline nodules in the amygdaloids fill cavities which were originally occupied by gas (like the air bubbles in ice,) the quartz, lime, &c., having passed in afterwards through the pores of the rock by infiltration. A very clear account of both processes is given by Daubuisson, *Geognosie*, Tom. i. p. 276, 2d edit. The same writer holds the paste of the older porphyries, and the substance of claystone, to consist of the matter of granite so intimately mixed that the parts cannot be distinguished, Tom. ii. p. 114, 1st edit. He terms it a "compact granite."

† Professor Jameson's Mineralogy of the Pentland Hills.—*Wernerian Memoirs*, Vol. *II. Pp.* 190, 194, 196.

Intermixed with the red porphyries are the following, which consist perhaps essentially of the same mineral substances, but are marked by a striking difference of aspect; *e*, a reddish-white porphyry with base of compact felspar, and crystals of augite; the crystals are thinly disseminated, and have a shining lustre on the fracture surfaces; there are numerous spots of red in the base, which are probably the same minerals in a state of decomposition. This is seen in a quarry 300 or 400 feet above Swanston, on the west side of the burn. *f*, A dark blue clinkstone, having the aspect of a greenstone at some parts, and at others of a basalt. This is found on a small crag about half a mile south-east of Swanston, and again a little higher. The same rock is also found at *g*, on the front of the most northern low crag, halfway between Dreghorn and Swanston. About a quarter of a mile west of Lothian Burn Inn, there is a dark blue amygdaloid. The cavities are small and very numerous, and when the inclosed nodules are decomposed, the rock assumes a cellular appearance. This bed only deserves notice because a rock very similar occurs in Loganhouse valley, and at West Kipps Hill. Below all these is a bed *h*, 100 feet thick or more, of a grey, or yellowish-white felspar. It is seen at Dreghorn Burn very near the Water-house, and is the lowest rock visible here. It passes into a claystone *i*, and may be traced down the small ravine in which the burn flows towards Dreghorn village, and in a ditch 100 yards westward. The lower parts of the bed look like a conglomerate, presenting round masses as large as the fist embedded in a base, but the inclosed masses and the base are of the same substance. Parts of it decompose in the water, become soft, and, being mixed with red matter, assume the texture of a sandstone.* There is a small wooded knoll perhaps twenty feet high, a quarter of a mile east from Dreghorn village, in which a reddish claystone analogous to this is found; and a similar rock exists in a long ditch-like ravine a furlong west from the Water-house.

The whitish felspar bed at the Water-house *h*, and the other somewhat higher, *e*, are of inconsiderable magnitude, but are adverted to because two similar rocks occur in analogous positions, about a mile westward, on the summit and northern declivity of Capelaw Hill, and may probably be the prolongation of these. The repetition of certain rocks is indeed too frequent in these hills to permit us to attach great importance to such facts; but the possibility of tracing particular beds over considerable spaces, is a circumstance of some value in all speculations on the origin of the rocks. Nor does it follow that the non-appearance of the bed at intermediate points proves an original want of continuity, since the connecting portions may have been swept away by subsequent changes. In reference to this subject it may also be stated, that the clinkstones resembling basalts and greenstones, seen on the low crags both east and west of Swanston, have their representatives in Loganhouse valley.

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* Trap rocks, especially claystone, sometimes decompose by the access of moisture, and pass into clay, still retaining the outward aspect of the original rock.—*Macculloch. System* i. p. 243. I met with another example at the east end of Turnhouse Hill, close to the margin of the pond.

In a field about half a mile right east from Dreghorn village, sandstone was formerly quarried; it dipped S.W. at 12° or 15°. About 200 yards west of Dreghorn House, within the parks, beds of reddish sandstone and blue slateclay are exposed in the burn, dipping S.W. at 28°. Rocks of the same kind (marked *h* in the section,) are also seen in Bonalley Burn, north of Dreghorn House, dipping S. about 15° or 18°.; and they are seen again farther up the burn, within half a mile of Bonalley, dipping S. at 10 or 12°. Thin beds of nodular blue limestone are inclosed in the shale here. No rock is visible as we proceed northward till we come to Colinton, about half a mile distant. Here beds of sandstone are found in the water course, dipping N.W. at 45° or 50°. The thickness of the sedimentary beds from Braid Hill to Slateford, an analogous position, at the distance of a mile eastward (see p. 98,) seems to justify the inference, that the highly inclined sandstone seen at Colinton, is continued southward near to the foot of the hills at Dreghorn, as represented in the section. The precise point of junction is of course matter of conjecture. It may be at *k*, or farther north, or farther south.

The sandstone is not visible at the other end of the section at *a*, but certainly exists there. It seems also probable that the beds dipping southward seen within Dreghorn parks and near Bonalley, are an upper and newer deposit, *h*, resting on the edges of the lower strata.

General Section, No. VI.

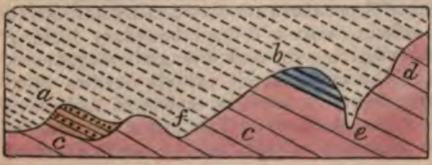
This passes in a north-westerly direction through Castlelaw, Capelaw, Torduff, and Warklaw Hills. Its length is exactly four miles.—See the line VI.VI., in the map of the hills.

In Glencross Burn, a furlong west from the Water-house, beds of shale may be seen dipping E.S.E. about 50°, and a few yards farther up there is a sandstone quarry in the copsewood, where the beds have the same dip. These are the beds *a* in the section. About a quarter of a mile above this the trap of the hill appears in the water-course, and is seen in several quarries on the east side of the road. It consists of various beds of clinkstone and felspar, generally porphyritic, red coloured, of different shades, but usually deep. At some parts it is amygdaloidal, and contains agates. Next to this is a vast mass of claystone passing sometimes into felspar, forming the principal part of Castlelaw Hill. The prevailing colours are white, reddish-white, and yellow; much of it is mottled, being ironshot with spots of red; and some of it is striped with hornstone. Its texture is generally compact, but some of the lower beds on the northern side have a gritty arenaceous surface, and are very white. I saw no traces of a bedded or stratified structure in this hill, though they probably exist. Under these are some red clinkstone; and a bed of blue clinkstone, approaching to basalt, *b*, is seen at the mouth of Allermuir Burn. Further up it assumes the appearance of a greenstone. It is possible that a bed of conglomerate underlies this at *c*. It is seen a little westward of the section between Harbour Hill and Bell's Hill. The cavity *c*, *b*, at Allermuir Burn, contains 100 feet or more of newer alluvium. Under these are the rocks of Capelaw Hill, which, so far as they are visible along the line of section, present themselves in the following order. A very light-coloured bluish-grey claystone porphyry, the weathered surfaces of which become red (at Capelaw Cot;) a reddish-grey porphyry, seen in a small quarry half a mile N.E. of the cot; a porphyry with a yellowish-white or cream-coloured base, the weathered specimens of which have spots of light red, dark red, and green (seen on the south side of the summit, but only weathered specimens accessible;) a reddish-grey porphyry with crystals of felspar, and others of a green colour, which assume a red colour in decomposing, and are probably augite, (seen at west end of hill;) a compact felspar of a brick-red colour tinged with yellow, (seen on the north front of the hill, 250 feet above the level of Bonalley old ponds;) a greenstone *d*, (seen about 150 feet above the level of Bonalley reservoir,) of the usual bluish-grey below, but of a deep red in its upper part; a reddish-white compact felspar, about eighty feet thick, lies under the greenstone, and is probably a continuation of the bed seen at the Water-house, near Dreghorn. At the south margin of the pond (now drained) we find a bed of sandstone *e*, and traces of it are met within a drain westward. It seems to be a remnant of a larger deposit, resting in a slight cavity of the porphyry, at the height of 1100 feet above the sea. It was probably once continuous with the sandstone *h*, *g*, in Section VII. From this to Torduff Hill there is a succession of porphyries and amygdaloids. They are well exposed in the bed of Dean Burn, which flows from the old reservoir to Bonalley, and also partly in the crags which rise above one another, from Lord Cockburn's garden to the top of Whitehill. The base of these rocks is sometimes felspar, but more generally clinkstone of a blackish-grey or reddish-brown colour. In the felspar there are occasionally intermixed portions of a different colour, with a defined boundary looking like embedded fragments, and giving the rock, though homogeneous, the aspect of a breccia. The amygdaloids exhibit cavities filled with green earth, quartzy minerals, zeolites, calcspar, and small rounded masses and veins of calcedony. The latter are seen in the crags rising above Bonalley village, on the north front of

Whitehill, and also at some places in the rivulet. The nodules sometimes form one-third of the mass of the rock. Generally the base is porphyritic, and contains long thin crystals or grains of white felspar. This is the third great bed of *quartziferous porphyry* from the east end of the hills, without reckoning smaller ones. The frequent changes of rock show the existence of beds, though the bedded or stratified structure is scarcely discernible, except towards the head of the burn. These are succeeded by Torduff Hill, *f*, consisting of a reddish-white hard compact felspar, assuming the character of claystone at some places. It is probably 200 feet thick, and seems to be of limited extent laterally, its breadth probably not exceeding 2000 feet. Beneath this is a dark greenish-grey felspar porphyry *g*, forming the summit of Warklaw Hill. It passes through a succession of beds into the blackish-grey greenstone, with minute grains of red (augite or diallage ?) seen on the west side of Turphin, and at Kenleith, and having much the aspect of a mechanical compound. The bedded structure of these rocks (see the section) is too well marked to be mistaken. They dip to the S.E. at 25° or 30°, and project beyond each other, forming a succession of terraces. Lady Burn, forming the north branch of Bonalley Burn, runs in a deep valley formed by the junction of the felspar rock *f*, and the porphyry *g*.

A little eastward of Turphin farm-house there is a crag of conglomerate *h*, about 100 feet high, with a dip to the south-east probably of 15° or 20°. The rolled fragments rarely exceed six inches in diameter. The base is less argillaceous, and more of the nature of sandstone than in the other conglomerates of the Pentlands. It may be a bed intercalated among the porphyries; but as no trace of it appears to the westward, where, on this supposition, we might expect to find it; and as its substance differs considerably from that of the other conglomerates of the hills, it seems more probable that it is a mass of sandstone resting externally on the porphyry, and lifted up with it. In corroboration of this idea it may be stated, that on the side of Dean Burn, about half a mile south-eastward, a large mass of sandstone and shale is found extending from Lord Cockburn's house, 500 or 600 yards up the hill (see the map,) and like this, dipping south-east at a pretty high angle (from 20° to 40°.) A section from Whitehill, which overhangs Bonalley, in a north-west direction to the conglomerate crag, would present an outline like this.

FIG. 51.



a, The crag of conglomerate at Turphin, assumed to be merely resting on the outer part of the porphyry.

b, The detached mass stretching up the hill from Bonalley.
c, *c*, The porphyry of the hills.
d, Whitehill.
e, Dean Burn, the south branch of Bonalley Burn.
f, Lady Burn, the north branch.

The position of the upper mass of sedimentary rock, *b*, is quite unequivocal. It rests on the porphyry, and is in no respect embedded in it, and must therefore have formed part of a much larger mass. It seems fair to draw a similar inference with regard to *a*, and to regard both as remnants of one deposit, which flanked and partly covered the hills, and was lifted up with them into its present inclined position. The dotted lines mark the portions of rock which are supposed to have been removed. The sandstone and shale *g*, *h*, seen at the west end of Torduff Hill, in Section VII., and extending southwards to Belld Hill, is probably part of the same deposit. It will be described by-and-by.

From Turphin northward no rocks are visible till we come to the Water of Leith at Woodhall, where sandstone and shale are seen nearly horizontal. Towards West Mill, half a mile down the river, the rocks are seen dipping N.E., at angles from 25° to 50°. The sandstone presents carbonaceous impressions of plants; and a black shale, containing terebratulites, is found here. Westward from Woodhall, the dip is various, but in general to the W. or N.W. at angles from 5° to 30°. The position of the sedimentary rocks, from Turphin to Woodhall, is merely conjectural.

SECTION, No. VII.

This section crosses the hills from Lawhead farm to Currie. Its length measured on the map is 4½ miles. The series of rocks is as follows:—

A clinkstone porphyry is well exposed in a quarry at Lawhead farm-house. It is of a brown colour, has a splintery or sometimes a conchoidal fracture, and contains crystals and grains of red felspar. Lawhead Hill, about half a mile eastward, is of the same rock. Northward of Lawhead farm, the rock is seen at some few places for more than half a mile: it is essentially the same, but the brown takes a greenish tint, and the aspect becomes nearly homogeneous from the minuteness of the embedded grains, while the fissile tendency displays itself which is so common in clinkstone.

Turnhouse Hill consists of a mass of clinkstone and claystone porphyries. On its south side there are traces of the stratified or bedded structure, which, judging from analogy, I have little doubt pervades the whole. On the southern declivity of the hill, and at its foot, we have a dark grey clinkstone (seen near the Compensation dam*) with a conchoidal fracture. In a quarry at the side of the road, close to the stream, a little farther south, it is of a red colour. On a wooded knoll, *b*, about 250 feet below the eastern summit, we find a felspar passing into claystone, and of various aspects: sometimes reddish-white and granular; sometimes spotted; sometimes having a grey or blue base, with white, yellow, or red spots and stripes. Close to the Compensation dam is found a rough white claystone porphyry, consisting of white angular grains in a yellowish-white base, and exhibiting specks and patches of brick-red, and even enclosing masses some yards in breadth of this colour. It may be traced about 300 feet northward along the side of the pond. The summit and northern declivity present the same white rocks, light bluish-grey claystones, and dark grey and red clinkstones passing into greenstones, but in what order and proportions cannot be ascertained, owing to the covering of turf. At the base of the hill there is a conglomerate *c*, now covered by the waters of the pond, but formerly noticed by Professor Jameson.†

The south end of Belld Hill, *d*, called King's Hill, consists at the top of a greyish-white compact felspar, exhibiting a laminar structure: at the bottom it is a greenstone *x*, having a considerable resemblance to that which is quarried 200 yards westward, behind Mr Robertson's lodge. The highest portion of Belld Hill, from *e* to *f*, is of the same greyish-white compact felspar seen at *d*. It is succeeded at *f* by a conglomerate forming a crag fronting the west. The latter contains rounded masses of all sizes up to half a foot in diameter, embedded in a granular base, of which one-third seems to consist of red or white felspar, with a little quartz and two-thirds of clayslate or the dark porphyry of the hills. Among the embedded masses are a few of felspar as big as an egg; but ninety-nine in a hundred of them are of the same nature with the base, only more compact and harder. There are traces of stratification in it; and the dip is south, from 40° to 60°. In the upper part of the hill the junction of this conglomerate with the felspar, so far as it is seen, appears nearly vertical (under *f*.) The two rocks are distinctly seen in contact; and the line dividing them runs north-east. At the point of contact the felspar assumes a slaty aspect; and the conglomerate becomes hard, though at a small distance the exposed surface is almost as soft as clay. On the top of the hill, at *f*, a depression in the outline marks the change of rock, which is there covered by the turf. The breadth of this conglomerate is about 150 yards, and beyond it, on the north, we have the dark grey greenstone *y*, which is similar to that found at *x* at the south end of the hill. It probably underlies the conglomerate; but their junction is not seen.

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* For distinction sake, I use the word *dam* for the mound which shuts the water-course, and forms a small lake; to the lake I give the name of the Compensation *pond*.

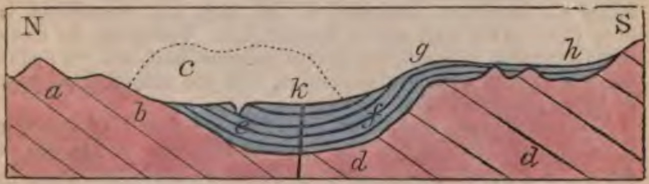
† Wernerian Memoirs, Vol. ii. p. 187.

The position of the mass of felspar in Belld Hill seems not to be accordant with the bedded structure, which I have supposed to exist in the porphyries. The hill, however, is so covered with turf, that very little of the rock is seen; and of course considerable uncertainty rests over the relations of its different parts. The conglomerate *f*, which divides the felspar from the greenstone at the north end, does exist between *d* and *x*. A mass of this substance, about ten feet long, is seen between *d* and *e;* but it is most probably a travelled block. The western and lower part of Harbour Hill consists of the same felspar seen in Belld Hill; and the conglomerate lies beneath it here too, for though not seen *in situ,* its debris are found in the turf in considerable quantity.

At *g* the greenstone is succeeded by beds of sandstone, dipping W.N.W. at an angle of 30°. A little way eastward, on the road to Currie, we find the same sandstone in a horizontal position. About half a mile N.W. of this, we find beds of red and white sandstone in Kenleith Burn, dipping S.W. at 20° or 25°. These beds continue almost to Kenleith village. We also find them half a mile eastward among the springs of Bonalley North Burn, from whence we can trace them down to the waterfall at the west end of Torduff Hill.

In this burn we get a pretty complete view of these sedimentary rocks. The following diagram conveys an idea of their position. It is a section south and north.

FIG. 52.



a, The greenstones of Warklaw Hill.

b, The felspar of Torduff Hill. This portion of the rock lies on the west side of the burn, and has been cut through by the stream, which afterwards flows on the line of junction between the dark porphyry and the felspar.

c, The position of Torduff Hill, which lies east of the line of section.

d, d, The continuation of the beds of porphyry, which are presumed to be the same with the rocks seen in Dean Burn.

e, f, Beds of sandstone, shale, and limestone; *e* marks the situation of the waterfall in the burn at the west end of Torduff Hill.

g, The upper waterfall, more than half a mile south from the other.

h, Thin horizontal beds of sandstone above it.

k, A greenstone vein.

The sedimentary rocks, *e, f,* are as follows:—Beginning with the lowest resting on the felspar of Torduff Hill, there is first, a sort of tuff formed of minute fragments of the felspar mixed with red clay; this passes into a fine-grained red sandstone, above which is a coarse-grained sandstone, largely mixed with grains of felspar of the size of pease, and exhibiting diagonal laminæ. These sandstones are seen near a waterfall at the west end of Torduff Hill; their dip is south, at 10° or 12°. About a quarter of a mile westward, a limestone conglomerate is seen about *e,* in a quarry, dipping south at 25° or 30°. Near this, at the remains of an ancient camp, the burn divides into two. Following the branch which comes from the south, we find, about *f,* sandstone and shale, with an opposite dip to the former, that is, to the north, the inclination of the strata in both cases having a general conformity with that of the ground. The shale is pretty abundant here, and of a light-blue colour. Near the ancient camp is a vein of crystalline greenstone, *k,* of which the part that is visible has a breadth of 12 or 15 feet. Its apparent direction is W.N.W. and E.S.E. Some beds of compact blue limestone, without shells, are found among the strata in contact with it. About half a mile above the camp, at *g,* where the ground rises suddenly, there is a waterfall. The sandstone is found here dipping to the north at 30°. It rests on a sort of conglomerate, composed apparently of small fragments of the subjacent porphyry, cemented by red clay, and resembling the lowest bed at the west end of Torduff Hill. Following the rivulet southward above the fall, the surface becomes level, and we find the sandstone, *h,* in a horizontal position, with the subjacent porphyry breaking through at intervals.

The sedimentary rocks just described are found at elevations from 600 to 1100 feet above the sea, and from 200 to 600 feet above the general level of the sandstones of Mid-Lothian. The question occurs, are they a remnant of the sedimentary strata, borne up with the traps of the hills when they ascended to their present situation? or have they been deposited upon the porphyries since that change took place? The high inclination of some of those rocks, and of the others on Dean Burn, at Bonalley, (in some parts 40°,) seem to me to preclude the supposition that they were formed after the porphyries were raised to their present elevation. The conclusion which best consists with the facts appears to be, that they belong to deposits which flanked and partly covered the hills *before* the last upheaval of the mass; that the fractured portions which ascended with the porphyries when first upheaved were much more extensive both in depth, and laterally, as shown in Fig. 51, p. 132, the outer and higher portions, marked by dotted lines, having been afterwards swept away, leaving only the remnants now visible; and that the diversity of dip and inclination in the incumbent sandstone are partly attributable to original inequalities in the subjacent rock, partly to dislocations produced by the upheaving movement. The greenstone dyke *k*, favours this last supposition. Indeed, the entire absence of such dykes in the porphyries of the Pentlands, would perhaps justify a doubt, whether the rock concealed beneath the sandstones here is of that class. The greenstone dyke two miles westward at Bevelaw, is in the clayslate. We now return to the General Section.

A dark-grey greenstone passing into clinkstone is found at Kenleith, forming the hill on which the village stands. It is well exposed in the rivulet, which has cut a ravine in it to the depth of nearly 100 feet. There are obscure indications of a southern dip in it, but at a lower angle than shown in the section. Towards the bottom, at *i*, there is a grey amygdaloidal calcareous claystone. It effervesces with acids, and has numerous cavities filled with calcareous spar. Sandstone is found near it, and the greenstone appears again below them. These may be embedded in the trap; but it is more probable that their position is analogous to that of the sedimentary rocks at *h* above, and at Turphin and Bonalley, *a* and *b*, Fig. 51, p. 132; in other words, that they rest on a projecting ledge of the greenstone. At the point where the greenstone disappears, it is succeeded by a series of beds of sandstone and shale, dipping S.W. at various angles from 10° to 40°, but averaging perhaps 20°. These extend to the Water of Leith, near Currie, where there is a bed or vein of greenstone, *m*. At the upper end, between these beds and the Kenleith trap, and at the junction, we find a few beds of sandstone, shale, and limestone, presenting their edges as at *k*, and standing in a position at right angles to the others. They are imperfectly seen owing to the covering of gravel; but where visible they dip to the north at 30° to 50°. Their breadth is about 80 or 100 feet. The most southern is a dark blue compact limestone, without apparent shells, but traversed by veins of spar. In the brook, about eight feet of gravel intervened between it and the greenstone, when I visited the spot in 1831. I found a second limestone, of a more earthy texture, a few yards lower, with some sandstone, and the beds dipping south were almost in contact with them. These beds are interesting so far, as they seem to indicate the existence of a line of fissure here, and thus to mark the outer limit of the trap rock in a northern ~~limestone~~ directi. It is easily understood that if a disruption took place, and the greenstone ascended here, it might break off, tilt, and carry up with it a portion of the sedimentary rock at the line of fissure. Had no beds been found in this anomalous position, we might have supposed that the strata *k*, *m*, rested on a ledge or projecting terrace of the trap, like the strata *g*, *h*, the one mass of trap being unseen, while the other has been exposed by denudation. It is still possible that this may be the case; but the tilted strata *k*, may be received as probable evidence of a fissure; and if a portion of the greenstone underlies the rocks *k*, *m*, we may infer that it was detached from the portion seen above *k*, when the latter was upheaved.

There is presumptive evidence that the porphyries of the Pentlands have been upheaved at their north side to the extent of some thousand feet; but the upheaval took place most probably by a succession of *lifts*, attended with disruptions, and affecting the strata to a considerable distance from the foot of the hills. This will be understood by a reference to what was said at page 107, of the Fife coal-field, where four *faults* throw up the coal strata 378 yards in a space of twelve miles. If we suppose the centre of the disturbing action to be in the Lomond or Ochil Hills on the north, we find that the part of the strata nearest them has been raised 378 yards, the next portion southward only 308 yards, the third portion 108 yards, and the fourth portion 64 yards. It seems reasonable to suppose, that the upheavals took place in this way. The first affected the whole four divisions of the strata, raising them 64 yards. The second left the outer division unmoved, but lifted up the three others 44 yards more. The third left the two outer divisions unmoved, but lifted up the third and fourth 200 yards more. The fourth left the three outer unmoved, but lifted up the fourth 70 yards more. These lifts not being vertical, but inclined at a considerable angle, the actual elevation of the fourth or highest division, according to Mr Landale, is only about 200 yards, while that of the summit of the Ochils here is perhaps 600. It is probable, therefore, that the three or four other faults occur between the upper limit of the coal-field and the foot of the hills, raising the inferior strata (calciferous sandstones) 100 yards or more vertically; and that, subsequent to all these changes, one, two, or more upheavals took place, confined to the porphyries of the Ochils alone, pushing them up 200 or 300 yards above the strata on their flanks, which had previously accompanied them in their movements. We have another example of similar changes produced by dislocations, in the Alloa coal-field, which will be adverted to afterwards.

SECTION, No. VIII.

THIS section extends in a north-west direction, from a point half a mile west of Silverburn, through Carnethy and North Black Hill to Balerno Burn and the Water of Leith. Its length is about four and a half miles. The series of rocks, beginning at the south-east end, is as follows:—

1. Clinkstone of a greenish-grey colour, *a*, seen at Lawhead,

and already described. This extends to the foot of the southern acclivity. 2. To this succeeds a large bed of porphyry, *b*, assuming many different aspects. In a quarry at the pass betwixt Carnethy and Turnhouse Hills, the base is a blue or purple claystone, thickly spotted with crystals of white felspar. The rock weathers deeply; the exterior portions, to the depth of six or eight feet, becoming yellow, or red and yellow in spots or stripes. A little below the top it is a hard white compact felspar, translucent at the edges; and at the top of Carnethy it is a greyish-white felspar porphyry, passing into hornstone. This rock extends about 200 feet beyond the summit on the northern declivity. 3. It is succeeded by a bed of bluish-grey greenstone, of small depth. 4. A bed of amygdaloidal porphyry, *c*, the base of which assumes a brick-red colour in weathering. It contains nodules and veins of quartz and agate, and may be traced a good way down the northern declivity, particularly on the west side. We have the same bed to the westward under South Black Hill,* and at the summit of West Kipps Hill, as well as far to the eastward at Kirkyetton Crag; and at each of these localities it occupies an analogous position, lying under a large bed of whitish claystone or felspar. 5. Under this is a bed or series of beds, *d*, of porphyry and greenstone, of which the base is generally greenish or bluish-grey: it is often fine-grained: sometimes compact; sometimes it is a greenstone translucent at the edges, as in a quarry at a small group of trees on the side of the burn; and sometimes it resembles basalt. In a quarry, *e*, a quarter of a mile west from Logan House, but higher up, it has the character of a greenstone; and we find the same rock eastward behind Mr Robertson's lodge, of a darker colour, and much veined.

At one spot on the side of the burn, under Carnethy, a small portion of conglomerate is found. It is about half a mile above Logan House. The pebbles are rounded, few being larger than an egg, and they are chiefly of old red sandstone. The mass is ten or twelve feet thick, and a few yards in length.

In a small burn coming from the north, at an old vaulted building supposed to be a chapel, there is a thick deposit of claystone tuff; it is of a mottled colour, yellowish externally, but blue in a deep fracture. It is regularly stratified, is 30 or 40 yards in depth, and dips to the S.E. at 25°. The dotted space between *d* and *e* marks the situation; but it is probably a local deposit, not reaching to the line of section. For distinction's sake I call the small burn (14 in the map) "Chapel Burn." 6. Under these rocks we have a vast deposit of flesh-coloured compact felspar, *f*, forming the principal mass of North Black Hill. Owing to a thick covering of peat, it is only seen at a few places. The surface exhibits numerous fissures, and it breaks into rhomboidal or apathose fragments, the length and breadth of which much exceed their thickness. It is generally of a flesh colour, and sometimes displays embedded crystals in faint white or grey spots. In the little burn (15 in the map) which flows eastward on the south side of the hill, it assumes the aspect of a rough claystone of a white or greyish-white colour, and disposed in laminæ, which are much contorted. At the north-west part of the hill also it passes into a claystone; and this, with the absence of all traces of a bedded structure, leads me to think that it is wrapped over the greywacké slate in the manner shown in the section. This rock differs a little from the felspar of Belld Hill; but the difference is not greater than might exist between two parts of the same igneous mass. The relations of the two hills, however, and of the adjoining rocks, do not favour this supposition. 7. The felspar rests on vertical greywacké slate, which is beautifully exposed at the head of the glen, westward of the line of section. The following is a view of the two rocks, as seen from a point about fifty yards distant. The horizontal extent of the slate *a*, *a*, is about 400 feet; and there is a second portion, about thirty feet in extent, displayed forty yards lower in the valley.

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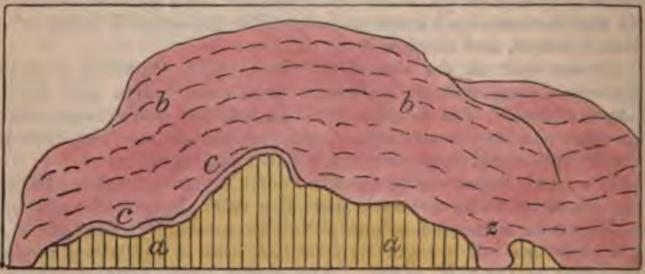
* There are two *Black Hills*; one termed simply "Black Hill," and the other "East Side Black Hill." To prevent mistakes, I have called the former North Black Hill, and the latter South Black Hill. Their relative position is exactly south and north.

Fig. 53.



a, *a*, The vertical slate; some of it is like primary clayslate, blue or greenish-grey coloured, hard and brittle; some of a light brown; some a deep red, a true sandstone, so soft as to yield easily to the knife.

b, *b*, The incumbent mass of yellow compact felspar, some hundred feet thick.

c, *c*, The appearance of the felspar at its junction with the slate is changed. The portion nearest the slate, to the depth of *four or five* feet, is of a grey colour; the next has a tint of red mixed with the grey; and about three yards above the slate, the felspar appears of its usual flesh colour. I take for granted, that a similar change in the state of the felspar exists along the whole line of junction; but it was accessible only at one spot, about fifty feet above the level of the valley.

The vertical slate is found again at the north-west corner of the hill, and a small portion at its north-east end, about 100 feet above the swampy hollow which divides it from Belld Hill. I have no doubt, therefore, that it exists under the felspar cover along the whole extent of the hill, on this side, as shown at *g* in the section.

The top of the North Black Hill has generally a covering of peat four or five feet thick; under this there are some yards of felspar, gravel, and bluish clay; and in these materials there are long and deep cavities hollowed out by the rain. At points where the peat is thin or entirely wanting, there are a few rolled masses of trap, conglomerate, and sandstone, of all sizes up to two cubic yards. On the steep declivity which forms the east end of the hill, there is a sandstone boulder of eight tons weight, about 400 feet above the adjoining valley, and at a part where the surface, both above and below, slopes at an angle rather exceeding 45°. The west branch of Chapel Burn flows in a small ravine, in which there are 50 or 60 feet of travelled soil, red-coloured and loose, a newer alluvium. Amongst it are seen blocks of felspar and sandstone, some of the latter of eight or ten tons weight. The felspar is evidently derived from the rock which caps the hill.

At the north foot of Black Hill, near Craigintarrie, we find the sandstone *h*. It is reddish-coloured, in thick beds, and dips W.N.W. at angles from 35° to 60°. The beds present their ends to the Black Hill, and seem from their position to lean against a projecting foot of Belld Hill.

Beyond this we find a great deposit of sandstone and shale, *i*, which may be distinctly traced in Bevelaw and Balerno Burns.* From Balerno up the water-course to the eastern angle, the dip is uniformly to the S.S.W., and at angles varying from 10° to 45°. Above the eastern angle, that is, in Bevelaw Burn, the dip is from 25° to 45°, and very nearly south. The lower part of the beds, towards the Water of Leith, consists of sandstone with a very little shale; the upper, which is seen in Bevelaw Burn, for half a mile from the angle, consists chiefly of blue and red shale, with little sandstone. The sandstone is generally firm and fit for building; but some of the upper beds are micaceous and slaty. There are some thin beds of limestone: one is seen at the eastern angle, another in the small branch stream which flows westward from

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* For the sake of distinction, I give the name of "Bevelaw Burn" to the part of the stream whose course is N.E.; and that of "Balerno Burn" to the lower part, from the point where the course turns to the N.W.

Craigintarrie; and there are several others. No black shale is visible in Bevelaw or Balerno Burns. Westward from Threapmuir the channel of the stream exhibits nothing but clay and gravel; so that the junction of the sandstones dipping to opposite points is not visible. It seems probable, however, that their position is as shown in the section. The vertical slate is not seen at *g*, but its existence there may be inferred.

Arrows have been inserted in the map of the hills, to exhibit the diverse inclinations of the sedimentary rocks just mentioned. In Balerno Burn (arrow *h*) they dip S.S.W.; those near the village from 10° to 30°; those farther up from 25° to 35°. In Bevelaw Burn and a small branch stream, (arrows *i* and *k*,) they dip nearly S. at 25° to 45°. In Kenleith Burn, (arrow *n*,) they dip S.S.W. below the village from 10° to 40°, above at 10°. At Craigintarrie, (arrow *m*,) they dip W.N.W. from 35° to 60°. At the north end of Belld Hill, they dip N.W. On the upper branches of Lady Burn, they dip N.N.W. (arrow *p*,) and S.S.E. (arrow *q*.) At Turphin, (arrow *s*,) they dip S.E.; at Bonalley, (arrow *r*,) S.E. Thence, eastward to Dreghorn, (arrows *t*, *u*,) nearly S.

The correspondence of the beds at *m*, in the lower part of Kenleith Burn, and at *h*, *i*, and *k*, render it probable that the whole are one continuous deposit. The distance on the map from *m* to *i*, where the strata disappear under the gravel, is fully two miles; and Threapmuir is 300 or 400 feet above the water at Currie. Estimating the mean dip at 20°, the entire thickness of the deposit, if *faults* do not intervene, will be 3500 feet. Even the strata exposed in Balerno and Bevelaw Burns, up to *i*, whose dip will average 20°, must have a depth of nearly 2500 feet. The abundance of blue shale in these strata, and in those to the eastward, at *p*, *q*, *r*, *t*, and *u*, with the frequent occurrence of thin beds of limestone, lead me to refer the whole to the upper part of the calciferous sandstones.

Bevelaw Burn exhibits a very beautiful specimen of the action of rivers in excavating their beds. From Balerno upwards the land on the opposite sides of the stream is evidently part of one continuous plain. At the eastern angle near *k* in the map, the ground presents an extremely slight rise of perhaps one foot in fifty on the west and east side of the stream, in opposite directions; showing, 1st, that the river, in turning from an easterly to a westerly course here, was determined by a very slight inequality of surface; 2d, that the levels have not been disturbed since; and 3d, that the excavation of the channel is entirely the work of the stream. The depth is in proportion to the rapidity of the descent. In the lower reach from Balerno to the eastern angle, the ravine is from 40 to 80 or 100 feet deep, and the fall great; but above the angle, where the course is comparatively level, the depth is small. A person laying his head on the grass within 20 yards of the river bank, would see the plain on the opposite side as a continuation of that on which he rested, and never suspect that a ravine of 60 or 80 feet in depth was close by him. Nearly all the fragments turned up on Threapmuir are of sandstone.

SECTION, No. IX.

THIS section extends from the high-road a little west of Silverburn, through the South Black Hill, across the Linn at Habbie's How[*] to Bevelaw Burn. (See the map.) Its length is about 3½ miles. The rocks at the south foot of South Black Hill, *a*, are similar to those at the foot of Carnethy. At various quarries or other openings, we find a greenish-grey and a bluish-grey clinkstone, streaked with red; a deep brown porphyry of the same species, sometimes amygdaloidal, containing small quartzy nodules coated with green earth; these are succeeded by grey or purple or white claystone and felspar, generally containing grains of a different colour, and forming the summit of the hill, *b*. On the northern declivity at *c*, about 200 or 300 feet below the summit, the claystone is seen in strata from half a foot to two feet in thickness, and subdivisible into thin laminæ; they dip to the S.E. at 30°. The surface is covered with herbage for 200 or 300 feet below this. In a rivulet, to which I give the name of South Burn, running right northward, and falling into Logan Water at the head of the glen, we have a good display of the rocks at the base of South Black Hill. In the descending order these are—

Below *c* we have a greenstone, which passes into a grey or red amydaloid, containing agate nodules, with others of quartz and calcspar, often coated with green earth. The largest I saw are about an inch in diameter. They are of a rounded or oval form, and the cavities in which they lodge have smooth surfaces. Sometimes the nodules are hollow, and have the inside coated with crystals, forming "drusy cavities." This rock is found at a corresponding height under Carnethy, and constitutes the summit of West Kipps Hill. Somewhere about *d*, there is a bed of breccia. It is seen in a quarry on the west side of the hill, about 300 feet above the farm-house of East Side, and is in thick beds dipping S.E. at a considerable angle, and seemingly passing under the porphyry, as shown in the Section. I discovered no trace of it in South Burn, but it may exist there; or it may be a local deposit of narrow extent. It is composed of angular fragments of the various porphyries on which it rests, sometimes a foot in breadth; among these may be distinguished the amygdaloid of West Kipps

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[*] *Linn*, in vulgar Scotch, a pool or lake, from the Gaelic *Linne*, and the Welsh *Llynn*, which are radically the same with the Greek λιμνη. The word is sometimes used for the rock which overhangs a pool, as in the Gentle Shepherd. The name of Habbie's *How* (Anglice *Hollow*) is given to the head of Logan House Glen, adjoining the waterfall.

Hill, grey clinkstones, and greenstones, like those of East Kipps Hill and South Burn; and flesh-coloured felspars like those of North Black Hill. The whole are united in a base of finer matter of the same description. Under the amygdaloid we have the greenstone again, which extends downwards over a space of perhaps 150 yards. It becomes gradually lighter, and passes into a claystone, and this, at the mouth of the burn, passss into a claystone tuff, *e*, of a mottled whitish-grey colour, disposed in laminæ. The tuff rests on a red slaty fine-grained sandstone containing mica, under which is a red claystone porphyry. These rocks dip S.E. at 40°. Next to this we have a common red sandstone *f*, seen at intervals along a space of 100 feet in the brook. The surface is much covered with herbage here, and the relative position of the different rocks can only be guessed at. From *f* to *h* we have a bed of conglomerate, about the middle of which, in a deep and narrow channel, *g*, is the waterfall of Habbie's How. The bed of conglomerate is probably 250 feet in depth, and consists of strata from one to three feet thick. In the lower part, at the waterfall, the inclosed masses are sometimes angular, and among them are pebbles of quartz, felspar, jasper, and flinty slate. In the upper part the masses are larger, sometimes nearly a foot in diameter, and with few exceptions beautifully rounded, and smooth in the surface like cannon-balls, as if they had been rolled for ages in water. They are generally of an elipsoidal form, and resting on their sides, rarely on their edges. Nine-tenths of the masses are of the same substance with the paste which unites them; it is a bluish-grey aggregate, formed of minute grains of quartz, felspar, clay-slate, &c., and of considerable hardness. They partake more of the nature of greywacké than sandstone.* Beds of the base, a few feet in thickness, alternate with the rolled masses. Two large detached portions of this conglomerate are found on the west end of North Black Hill, opposite the waterfall. In these, a half or two-thirds of the paste of the lowest beds consists of the flesh-coloured felspar on which they rest, worn down to the state of coarse or fine sand. There are numerous angular fragments of the felspar also, but few rounded pieces of large size, owing no doubt to the tendency of the rock to break into small portions. In the upper beds, on the other hand, the paste consists almost entirely of comminuted clayslate or greywacké, or older portions of the conglomerate itself, and the rolled masses consist of the two latter substances with few exceptions. The direction is nearly at right angles to that of the other rocks in the Eastern Pentlands, the dip being S.S.W. at 20° or 24°. The stream has cut a passage in this conglomerate above the cataract to the depth of eighty or a hundred feet, and extremely narrow. If we pass along the burn about half a mile westward from the waterfall, we find the conglomerate alternating several times with a soft red sandstone of the ordinary kind, in large flags; and at one point, about 200 yards from the cataract, we find a thin bed of limestone in nodules, similar to the limestone found a mile northwards near Bevelaw.

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* Professor Jameson says: "The very small granular varieties of this rock, which are principally composed of felspar and quartz, are very nearly allied to the greywacké of this district; indeed, in some instances, it is difficult to distinguish the one from the other in single specimens."—*Mineralogy of Pentland Hills, Wern. Mem.* vol. ii.

At the bottom of the conglomerate, and fifty yards from the linn on the left, a small portion of a bed of the flesh-coloured felspar is seen; and as we pass northward, we find the same rock assuming the character of a claystone at a greater elevation from *h* to *i*, on the west side of the ravine. It is a portion of the mass which forms the cap of North Black Hill, and may be seen every where on the opposite or east side of the ravine.

About 100 feet of rough sandstone mixed with some conglomerate is seen at *i*, on the north side of Hare Hill. It is probably a part of the beds seen in the burn above the cataract, and which certainly form the upper part of Hare Hill. The rock is nowhere visible on the summit of this hill, owing to a thick covering of heather, but large tables of a soft reddish sandstone, dipping westwards at 10°, are found near the footpath, and in the burn towards 12 on the map.

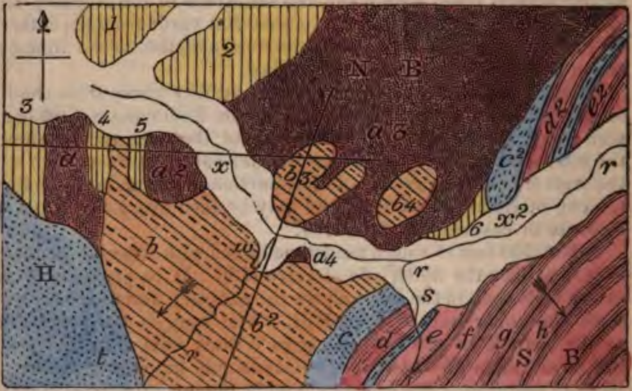
In juxtaposition with the sandstone at *i*, we find the vertical slate. It is clayslate, but mixed with beds of the fine-grained greywacké. This slate also constitutes the projecting foot of North Black Hill, which is seen on the opposite side of a marshy hollow, 100 feet deep and 200 feet broad. Over a space of half a mile westward, *k*, the slate is seen at intervals where the herbage is wanting. At some places it is much decomposed, and soft enough to be kneaded by the fingers, yet still retains the usual structure; and at others, portions of the claystone are seen in contact with it.

A vein of greenstone, *m*, near Bevelaw House, is found in the slate, having the same direction, that is, N.N.E. It is about fifteen or eighteen feet broad, and in transverse prisms.

About a quarter of a mile from the vein is an old sandstone quarry, where we meet, however, only with broken pieces; but about half a mile farther west we find the sandstone *n*, *in situ*, at an old lime quarry, (see the Section.) It dips W.N.W. at 10°. The limestone is of a grey colour, compact and hard, with a splintery fracture. It is similar to the limestone found above the waterfall, and to the thicker bed found in Mr Ferrier's quarry at Mickle Knock, four miles westward, (at 4 in the Map.) At Bevelaw the bed seems to be from two to three feet thick.

The position of the rocks at this locality is complicated and interesting. It is one of the spots which should be carefully studied by those who would investigate the structure of the hills, and some details will, therefore, not be out of place.

FIG. 54.



The above is a miniature map of the space at the head of Logan House Glen, called Habbie's How, with the parts adjacent.

N. B. The west end of North Black Hill.

S. B. The northern declivity of South Black Hill.

H. Hare Hill.

r, r, r, Logan House Burn.

s, South Burn, which flows from South Black Hill.

w, The waterfall, marked *g* in the General Section.

x, x^2, The white space is the low alluvial soil along the stream. The arrows indicate the dip of the rocks.

1, 2, 3, 4, 5, 6, Portions of the vertical slate, the fundamental rock of the hills; 6 is the portion figured at page 140.

a, a^2, a^3, a^4, The flesh-coloured felspar which covers the slate: at a and a^2, and on the part of Black Hill next to 2, it is a claystone.

b, b^2, The beds of conglomerate which partly cover the felspar.

b^3, b^4, Two detached portions of the same conglomerate, on the west end of North Black Hill, and with the same dip.

c, A portion of sandstone, 100 feet in breadth, seen at the mouth of South Burn, *s*.

c^2, A portion of perfectly similar sandstone, and of nearly the same breadth, seen near the vertical slate 6, on the north side of the valley.

d, A bed of reddish claystone porphyry, also seen at the mouth of South Burn.

d^2, A bed of reddish claystone porphyry, resembling a sandstone, and assumed to be a continuation of *d*. Above this is a red slaty sandstone, marked by a narrow dotted space between *d* and *e*. A similar deposit is found between d^2 and e^2.

e, A light-grey mottled claystone, passing in its lower part into a claystone tuff, in laminæ from 1 to 6 inches thick, and resting on the slaty sandstone.

e^2, The continuation of this on the other side of the valley.

f, A bluer and more compact claystone.

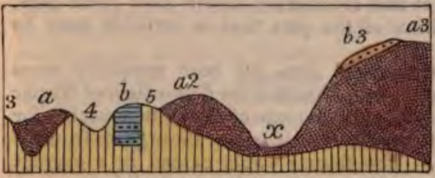
g, A greenstone, which covers an extensive space in South Burn. Both *f* and *g* are found on the north side of the stream. *g* is first met with near Chapel Burn, (14 in the large map of the hills.) It spreads out to a great thickness, and is found in quarries behind Mr Robertson's shooting-lodge.

h, The amygdaloid, described p. 139, which does not seem to cross Logan House Burn. The greenstone *g* assumes different aspects. It is fine-grained; sometimes compact, passing into a clinkstone; sometimes contains thin veins of white quartz, as in Mr Robertson's quarries. And *e*, *f*, and *g*, pass into each other by insensible gradations.

i, The sandstone forming the top and western declivity of Hare Hill.

The interior boundaries of *a*, a^2, *c*, c^2, and of 3, 4, 5, cannot be seen, and are, therefore, merely conjectural. The relative position of the rocks will be a little better understood from the two sections below.

FIG. 55.



Section along the line *a*, *a*3.

The letters and figures here correspond with those in the little map.

3, 4, 5, Portions of the vertical slate exposed in an abrupt declivity at the north-east foot of Hare Hill. Thin beds of greywacké are frequent in the slate.

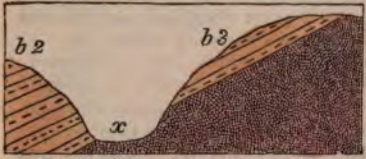
a, A mass of greyish-white claystone, resting on the clayslate, which here dips westward. The claystone is in strata from a few inches to two feet in depth, where it is in contact with the slate, and has the same dip. This laminar structure is most probably the effects of cooling. I infer that the claystone merely fills a hollow in the vertical slate here; and I think there are similar isolated masses in contact with the slate farther west.

b, A mass of sandstone occupying a cavity in the slate. It is a coarse sandstone, passing into conglomerate at the bottom, and is about one hundred feet in breadth.

a^2, The claystone is seen *in situ* low down, and in the ravine above x we have its gravel every where breaking through the soil. It may be safely assumed that the vertical slate exists under it here, as shown in the figure, though it is not visible.

b^3, The more northerly detached mass of conglomerate on the west end of Black Hill, with the flesh-coloured felspar below it.

FIG. 56.



Section along the line $b2$, $b3$, in the map.

The letters in this section also correspond with those in the map.

b^2, The strata of conglomerate at the waterfall.*

b^3, The detached mass on the west end of North Black Hill.

x, The alluvial bottom of the valley, covered with gravel. The felspar probably exists under x, for there is an isolated mass, marked a^4 in Fig. 54.

A few theoretical remarks are necessary to elucidate the complicated relations of these rocks, as to some of which, however, it is difficult to speak with certainty.

1. The appearance of the vertical slate at 1, 2, 3, 4, 5, and 6, leaves no reason to doubt that it underlies all the other rocks here, though the precise position of the part that is invisible must be matter of conjecture.

2. The surface of the vertical slate had been unequally worn down by water, and above it was deposited the flesh-coloured felspar a, a^2, a^3, in a state of fusion, or at any rate of high temperature; for the rock is discoloured to the distance of two or three yards from its junction with the slate. The felspar would extend in a current over the slate, filling up cavities and lessening inequalities.

3. The other porphyries d, d^2, e, e^2, f, f^2, &c., Fig. 54, were deposited above the felspar; and in the intervals between the eruptions of igneous matter, the play of the water on their exposed surfaces would, in some cases, and at some localities, generate tuffs such as we find in South Burn between d and e, and in Chapel Burn near e^2, where we have beds of claystone tuff one hundred feet thick; or conglomerates, such as we find opposite Chapel Burn, and above Westside Farm, (d in Section IX.)

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* In the character employed to distinguish the conglomerate in the diagrams, a hint has been taken from its structure, which sometimes presents alternations of rolled masses and granular beds. But it is used as an arbitrary symbol or hieroglyphic merely. The number of white and dotted spaces does not indicate the number of alternations; and in cases where the rock consists entirely of one kind, the alternations are still employed in the diagram.

4. In a cavity amidst these rocks, either original, or produced by aqueous denudation, the strata of conglomerate b, b^2, b^3, b^4, Fig. 54, were formed by the long-continued action of water on the pre-existing rocks, but chiefly on the clayslate and greywacké found westward and northward. These strata seem to me to occupy a cavity, as shown in General Section, No. IX. Their breadth from f to h may be one thousand feet. Their length from a^3, Fig. 54, to where they are succeeded by the sandstone in the burn near t, may be two thousand or three thousand feet. Their entire depth is probably three hundred feet. My first impression was that the conglomerate formed a bed among the porphyries, like d or e, (General Section, No. IX.,[*]) but this conclusion seems untenable for two reasons. First, not a trace of it is visible in the ravine of South Burn, at e in the section, where, on this supposition, it should have been found. Second, the beds d, e, f, &c., distinctly cross the valley, and reappear in d^2, e^2; and the conglomerate should, in this case, have been found under d^2, that is, in the position occupied by the sandstone c^2, where it is not seen, and would have been seen if it had existed.

5. The sandstone c, c^2, admits of two explanations. It may be a component part of the vertical slate. Among the beds of that rock at 6, close adjoining, are some of red sandstone one or two feet thick, and not distinguishable from it in hand specimens. Where seen at c^2, it stretches up vertically eighty or one hundred feet, till it is lost among the heather; and the true vertical slate reappears on its east side. It occupies the space z in Fig. 53, p. 140. The want of the stratified structure, however, either vertical or transverse, is adverse to this supposition; for all the part that is visible seems divided by fissures into irregular angular fragments, like some traps. Or, secondly, as the vertical slate probably once occupied the greater part of the space from x^2 to s, (Fig. 54,) we may suppose that, in the progress of the waste which has removed it, a cavity was cut which was filled by the sandstone then forming, probably the upper beds of Hare Hill. In this case c^2 may be merely the remnant of a mass which extended across the valley from x^2 to s; and instead of being *embedded* in the vertical slate, it may be merely *leaning against it*. The reader must keep in mind that we merely see opposite x^2 a small breastwork of sandstone; but whether it extends one yard northward or one hundred yards, we have no means of ascertaining. At s again, we see nothing but isolated parts in the brook of what seems to be a bed, but of its extent southward we have no knowledge. The form assigned to c and c^2 in the miniature map, is merely hypothetical.

6. Previous to the deposition of the great bed of conglomerate

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[*] In this, as in the other General Sections of the hills, the spectator is supposed to look eastwards. The parts from e to i, however, can be seen from the end of North Black Hill by a spectator looking westwards, but in reverse order, what is here on the right hand being there on the left. The Section Fig. 55, is also seen in reverse order.

in the cavity *h, f,* the porphyries had been raised into an inclined position; but not that which they now exhibit. Their dip will, perhaps, average about 30° to S.E., while that of the conglomerate is above 20° to S.W. Since it is plain that strata composed of rounded globes, must have been formed in a position almost strictly horizontal, a movement which these underwent must have raised their north-east, or depressed their south-west side. This was certainly a local and limited movement, chiefly affecting North Black Hill and Hare Hill; for the dip and direction of the beds of conglomerate, and of the sandstone covering it, differ from that of all the adjoining rocks where the stratified or bedded structure is visible.

If the conglomerate was formed after the porphyries of East and West Kipps Hills, and lies in a cavity at their foot, as here supposed, fragments of the rocks of these hills should be found even in the upper beds. I have not seen them there, however; but it is right to add, that I did not search for them so diligently as to warrant the assertion that they do not exist.

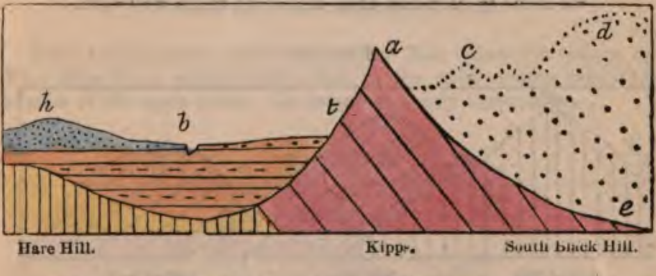
7. The movement which raised the north-east side of the conglomerate, probably caused a dislocation along the line of Loganhouse Burn, and by shattering the rocks, aided the water in excavating, or rather deepening, that valley. It seems reasonable to suppose that the valley owes its existence to two causes. First, to the original position of the rocks, the upper beds not completely covering the lower ones, but leaving angular spaces, which became cavities when the inclined position was assumed. Second, to denudation, for we cannot suppose that currents of fluid matter could be heaped one above another, with their exposed sides forming mural precipices, such as the north sides of Carnethy and South Black Hill would be if the beds were brought into the horizontal position. (See General Sections VIII. and IX.) Further, we find that the line of the valley crosses the beds, as shown in the miniature map. From the correspondence of the beds, however, on the opposite sides of the valley, it seems probable that the dislocation was not great.

8. It is plain from the truncated appearance of the conglomerate strata near the waterfall, and the isolated portions of them on the west end of Black Hill, (see Fig. 54,) that they once extended across the ravine x, leading to Bevelaw, and also in an easterly direction towards x^2. It is not impossible, therefore, that they might originally occupy the whole valley, and that both the strata between Belld Hill and Harbour Hill, (at 16 in the general map of the hills,) and the small portion opposite Chapel Burn (14 in the map,) may belong to the same deposit. But the latter seems not to be merely in contact with the beds of Carnethy, but to pass under them, and the entire disappearance of every remnant of the conglomerate from both sides of the valley, is a fact adverse to this supposition. Again, what origin are we to ascribe to the conglome-

rate at the north-end of Belld Hill? (*f* in General Section, No. VII.) It closely resembles the lower beds of Habbie's How (seen at b^3 and b^1 in the miniature map,) particularly in the abundance of red or flesh-coloured felspar in the paste. This, apparently, could only be derived from the felspar of North Black Hill, from which it is divided by the open ravine called Den's Cleugh. In that case the fair inference would be, that it was formed at the same period with the conglomerate of Habbie's How, and that the two are merely remnants of a much more extensive deposit which may once have covered the whole hill. The position of the eastern conglomerate, however, which dips at 45° to S.S.W., and the entire absence of a similar rock in the intervening space, so far as it can be examined, are circumstances not very consistent with this idea.

Kipps Hill and Broad Law.—These hills lie between General Sections IX. and X. Kipps Hill has the shape of a pointed cone, with concave sides: a section of it, in a N.W. and S.E. direction, would present this appearance :—

FIG. 57.



a, The summit of this conspicuous hill is a sharp ridge, about 200 feet long and six or eight broad: the rock is in beds dipping to the S.E. at 40°. The upper is the amygdaloid, repeatedly described already. The nodules are generally coated with green earth, often long-shaped, many of them like beans, and some like fingers. This peculiarity characterises the cells of lava currents, the length of the cells indicating the direction of the current. I examined the rock with a reference to this point, and thought that the length of the long-shaped cells generally corresponded with the dip; but the examples were not numerous enough to entitle me to speak with confidence. Below this rock lies one of a dark-grey colour: it is an amygdaloid also, containing grains of calcareous spar (and probably other minerals,) which weather out, and give it a cellular appearance. It is largely exposed on the western flank of the hill. The northern declivity is covered with turf; but I have assumed that the conglomerate of Habbie's How lies above these beds, as shown in the Figure. The inclination of the beds is made greater in the diagram than it is in nature.

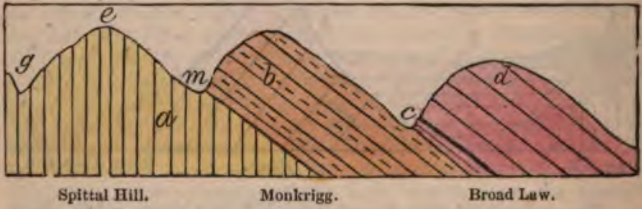
b.Loganhouse Burn above the waterfall, with Hare Hill, *h*, to the left.

c, East Kipps Hill, which lies east of the line of section, and is represented in shade. It consists of a porphyry with a red base, and small white crystals of felspar, with a few grains of green earth. A similar rock is found down in the valley at *e*, in the water-course, 800 feet below *d*.

d, South Black Hill, also in shade.

t, The supposed junction of the conglomerate and porphyry, corresponding to *f* in Section IX. Broad Law lies three quarters of a mile south of the two Kipps Hills, and Monkrigg Hill extends northward from it. It is here that the porphyries which compose the eastern mass of Pentland Hills terminate. Beyond this there is little porphyry till we come to Mendick Hill, about six miles westward.

FIG. 58.



This is a section in a south-east direction from Spittal Hill and the upper part of Monk Burn to Broad Law.

m, Monk Burn. The vertical slate *a*, is seen in the upper part of this rivulet, and can be traced over Spittal Hill, *e*, to Gutterford Burn, *g*.

b, The overlying conglomerate of Monkrigg Hill.

c, The upper beds of this conglomerate, which are well exposed in the rivulet on the west side of Broad Law. They are partly slaty, and dip, like the others, S.E., at angles from 30° to 45°. They seem distinctly to pass under the felspar.

d, A mass of flesh-coloured compact felspar, 300 or 400 feet thick, of a rounded shape, forming all the upper part of Broad Law. This felspar may be examined in a quarry on the south side of the hill. It has a slaty structure, and closely resembles that of North Black Hill in texture and colour.

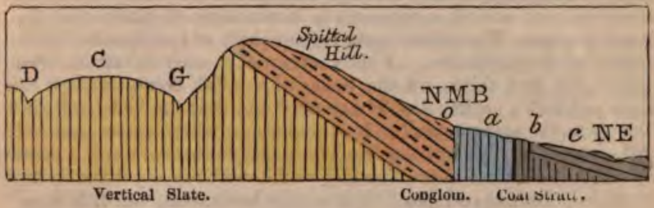
In a small hill, a quarter of a mile south from Broad Law, we find the compact greenish-grey clinkstone, with a slaty tendency, which is seen at the foot of Black Hill, Carnethy, and at other places on the south side of the eastern Pentlands.

In Monkrigg Hill the traps of the east end of the Pentlands unite with the conglomerates, which are so largely developed in the west. The ridge is of very small breadth; and while we find conglomerates every where on the west side, we find traps every where on the east. If we proceed along the east side of Broad Law and Monkrigg from the south, the rocks meet us in the following order:—1. The flesh-coloured felspar of Broad Law. 2. A dark-grey porphyry, seen on the road at West Side Farm. 3. An amygdaloid with large white grains, partly of calcareous spar, which weather out, and leave it cellular at the surface. If we travel along a line parallel to this, but 600 yards to the westward, we find every where conglomerate.

SPITTAL HILL AND NINE MILE BURN.

This small section extends from the Esk below the village of Nine Mile Burn, across Spittal Hill, to the most remote northern branch of the same river. Its length is nearly three miles.

Fig. 59.



D, Deerhope Burn, a branch of the North Esk.

C, Cockrigg Hill, the summit covered with heath, but showing vertical slate round its skirts. The direction N.N.E. and S.S.W.

G, Gutterford Burn. There are beds of greywacké, from one to two feet thick, mixed with the slate here.

Spittal Hill is composed of alternating beds of granular and rolled conglomerate; dip 35° S.E.

N.M.B., The village of Nine Mile Burn, marked *o*.

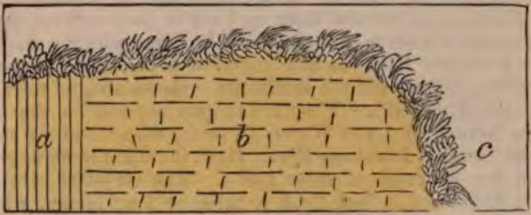
N.E., The North Esk.

The conglomerate disappears under a covering of clay and soil, a few yards north of the village. The same alluvium continues for nearly a quarter of a mile down the course of the rivulet. Below this, in the narrow ravine cut by the stream, we have a fine display of great beds of shale, *a*, part blue and red, part of the black bituminous kind, approaching to coal, with shining curved cleavage surfaces. With this there are intermixed some beds of sandstone, full of vegetable impressions; and I saw one bed of limestone three or four feet thick (marked with a heavy line.) The strata have a N.E. and S.W. direction, and are perfectly vertical; or, where they deviate from this position, they generally dip in towards the hills. These edge strata continue for about 400 or 600 yards, when, at *b*, we come all of a sudden to the strata *c*, nearly horizontal.

The space at *b*, which divides the vertical from the horizontal sandstone, in the bed of the stream, is only about fifteen feet in breadth. It is filled with gravel. The banks above are clothed with herbage and shrubs; and I was not able to ascertain whether the division forms a vertical fissure, or whether the level beds pass over the ends of the vertical, so that the latter would be found under *c*, as assumed in the Figure. The first of these level beds visible is sandstone, and about six yards thick; the next is of dark-coloured soft shale, containing layers of clay ironstone, and is of nearly the same thickness: then follow various sandstones, approaching to a dead level as we advance towards the Esk. The uppermost beds, which are well exposed in a waterfall at the junction with the valley of the Esk, are about sixty feet deep, without any admixture of shale; the superior strata are thin; the lower are thick, and exhibit carbonaceous impressions of plants and diagonal laminæ. The plants seem to be chiefly of two species, *Calamites* and *Lepidodendra*. This sandstone is seen in strata from one to six feet thick, on the banks of the Esk down through Sir George Clerk's parks; and I have no doubt that the beds at Roslin belong to the same deposit. It is sometimes white, sometimes reddish-coloured, large in the grain, and weakly coherent; and a depth of 100 feet or more is occasionally visible without any intermixture of shale. Its general position is nearly horizontal, but it is sometimes considerably inclined. I have traced it from Carlops down to Pennicuick, a distance of six miles by the river. The evidence which I thought I had found at some places of its resting on the ends of the older sandstone, was rendered doubtful by its appearance at others; and though satisfied that it is newer than the edge strata seen at Nine Mile Burn, I have not been able to ascertain precisely the mode in which it is connected with them. Some specimens of it which I examined in the parks of Newhall, consisted of *rounded* grains of quartz, united by clay or felspar, which weathers out, and renders the exterior parts cellular. The next section, however, will present an opportunity of reverting to this subject.

About a furlong north from a ruined cottage called Deerhopefoot, near the termination of the section, the slate presents the following singular appearance at the west side of the stream.

Fig. 60.



a, A portion of the greywacké slate, which had been traced for nearly a mile along the stream. It is of the usual appearance in laminæ, one or two inches thick, and perfectly vertical.

b, Brownish-white sandstone, in horizontal beds from two to three feet thick. In its texture it presents scarcely any thing to distinguish it from many of the common sandstones of the coal measures. The surface exposed is about fifty feet in length, and thirty in height. It lies in contact with the vertical slate, as closely as well-joined masonry, without the slightest appearance of disturbance.

On first seeing this, I concluded that I had found what I was in search of, the junction of the sandstone seen in Cairn Hills, with the vertical slate. This proved a mistake. For a hundred feet northward, the surface *c*, is covered with herbage. Beyond this is a deep and narrow ravine, in which the vertical slate reappears. Was this then a detached portion, a *vein* of sandstone? A more careful examination of the rocks here, and at other parts of the hills, afforded what seemed to be a satisfactory explanation. It is doubtless familiar to experienced geologists; but as the present Sketch is intended for beginners, who may be puzzled with facts like this for which the common Manuals and Systems have not prepared them, a short explanation may be forgiven.

In examining the greywacké farther up this burn, on Gutterford Burn, in the burn on the north side of Deerhope Rig, and in the upper branches of Lyne Water, I found that it assumed a great variety of appearances. It is sometimes a blue or green fissile substance, very similar to primary clayslate; sometimes a bluish or greenish-grey non-fissile rock, hard and heavy, and externally like a greenstone. Sometimes it has a brown or yellowish-white colour, a concoidal fracture, considerable hardness, and somewhat resembles a compact felspar. Sometimes this brown-coloured rock is softer, and looks as if composed of powder of felspar. Sometimes it is coarser in the grain, and becomes a common brown or yellow sandstone, with or without mica. Finally, Sometimes it is a soft deep red-coloured micaceous sandstone, noways distinguishable from the red sandstone lying under the coal measures. Indeed, the rock best entitled to the name of "Red Sandstone" in Pentland Hills, is to be found in the vertical slate, and not in the overlying strata.

All these varieties may occasionally be found within a small space. In the Pentland Hills the blue coloured is the most commcn ; but the brown, yellow, and red sandstone varieties abound towards the north side of the hills. They are largely exposed in the main or eastern branch of Lyne Water, (5 in the map,) and its tributary rivulets, towards Deerhope Rig. Now, there is a remarkable diversity in the structure of these rocks. The clayslate is in laminæ from a quarter of an inch thick to three or four inches, which are indefinitely subdivisible. In the other varieties, especially the coarse-grained, the laminæ are much thicker, reaching sometimes to several feet. These thicker vertical laminæ are rarely subdivisible; but, on the other hand, they have generally numerous transverse joints, which separate them into prisms or tables, lying across the laminæ, like the columns in trap veins. The coarser the grain, and the less coherent the substance of the rock, the longer, broader, and more conspicuous these transverse divisions become, till in some the vertical divisions disappear, and the rock exhibits the perfect structure of sandstone. I consider the rock *b*, in the preceding diagram, to be of this description. On examination, it proves to be extremely similar in substance to the vertical slate, *a*, in contact with it. The horizontal beds are lighter in the colour, coarser in the grain, and less coherent. They are the extreme term of the series, every intermediate member of which may be seen in some of the localities mentioned, and by which the finely laminated vertical clayslate passes into a gritty horizontal sandstone of little coherence. Other specimens, quite as coarse, or coarser in the grain, may be seen near Deerhopefoot, in the vertical position, but they seemed to me to be harder and firmer. The solution of the problem, then, I conceive to be this, that the vertical portions had consolidated and parted into laminæ *before* they were subverted and set on edge, while the horizontal portions had not undergone a similar change till *after* the series was tilted. That some of these rocks were still soft when they were thrown into the vertical position, seems proved by the sharp angular contortions the slates often exhibit.

In a small burn close to the horizontal beds I have been describing, (at 9 in the map,) I found two fossil specimens, the only ones, so far as I know, which have been discovered in the oldest rock of the Pentland Hills. I have no doubt that a diligent search in the same locality, would bring to light many more. I visited the place twice afterwards, but in unfavourable circumstances.

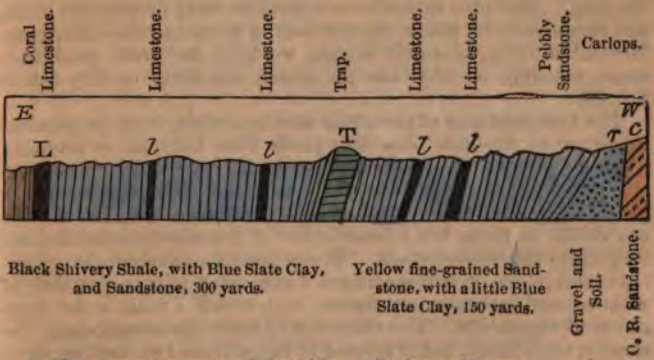
SECTION, No. X.

THIS section extends in a N.W. direction from the neighbourhood of Carlops, through Mount Maw, to the northern declivity of West Cairn Hill. Its length is about five miles. The greatest elevation of Mount Maw, according to Knox's map, is 1701 feet, and of West Cairn Hill, 1764.

Near Carlops we have the best opportunity of tracing the relations of the coal measures, and inferior sedimentary strata, with the old red sandstone of the hills. At the bridge in Carlops village, and upon the new road eastward of it, the conglomerate or old red sandstone is well displayed. In the course of the Esk, for three furlongs below Carlops, we have a series of newer strata, terminating with the coral limestone at an old bridge.

The following is a section.

FIG. 61.


Coral Limestone.
Limestone.
Limestone.
Trap.
Limestone.
Limestone.
Pebbly Sandstone.
Carlops.
E
W
L
l
l
T
l
l
r
c
Black Shivery Shale, with Blue Slate Clay, and Sandstone, 300 yards.
Yellow fine-grained Sandstone, with a little Blue Slate Clay, 150 yards.
Gravel and Soil.
O. R. Sandstone.

c, The conglomerate of the hills at Carlops village.
r, Gravel and soil.
T, A bed of trap.
L, The coral limestone, forty feet thick.
l, l, l, l, Smaller beds of limestone, interspersed amidst the sandstone and shale.

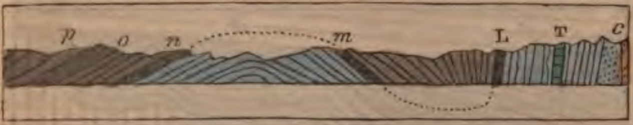
For fifty yards below Carlops, nothing but clay and gravel is to be seen in the bed of the river. We have then a series of sandstone strata intermixed with a little shale for 300 yards, but the river strikes them at an oblique angle, and their thickness will not exceed 150 yards. Towards the village, near *r*, is one conspicuous bed, soft, yellow-coloured, about eight feet thick, and containing pebbles of felspar, clayslate, old red sandstone, flinty slate, quartz, and limestone, of various sizes up to a breadth of two inches. It dips S.S.E., at 30°. The other sandstones of this section, so far as I examined them, are yellow, fine-grained, and rather soft, and seemed to be conposed almost entirely of minute grains of felspar. Some of them dip at 60° to S.S.E., and others are vertical. Beyond these we come to a bed of trap, dipping S.E., at a high angle, and apparently twenty feet thick. It is rendered conspicuous by a swell in the surface of the ground above, (see the diagram,) arising no doubt from the greater resistance its firm texture offered to the denuding agents. It is of an earthy aspect, and is rendered amygdaloidal by cavities filled with calcareous spar, and is, very probably, a continuation of a bed seen in a small ridge about two furlongs west of Carlops village, through which the road is cut. Proceeding down the burn, we have beyond the trap, for 300 yards, a series of beds nearly vertical. A very large proportion of these consists of a glossy black bituminous shale, much contorted, and intermixed with some thin seams of coal. There are also some blue shale, and beds of the yellow fine-grained sandstone; but the latter is in much smaller proportion than in the space between Carlops and the trap. The beds of shale are sometimes forty or fifty feet thick, and impressions of plants abound both in these and the sandstones. Beyond all these, at an old bridge, we have the great coral limestone, standing on edge like the others, and forty or fifty feet in breadth.

The true thickness of the strata now described, from the encrinal limestone to the beds seen fifty yards from Carlops, is probably about 1200 feet. In this space there are at least four beds of limestone, the places of which will be seen in the diagram. They are grey-coloured, hard, and have a splintery fracture. No large shells are visible in them, but I found a few of the microscopic kind belonging to the entomostraca. There are also some specks of pyrites, and in one or two specimens I saw many minute portions of what seemed carbonaceous matter, and which I took to be fragments of vegetables. The thickness of these limestones cannot be exactly ascertained, but it seemed to range from two feet to eight or ten. I consider these as the equivalents of the Burdiehouse limestone.

The black shale is also to be seen in a rivulet which crosses the road about half a mile east of Carlops.

I traced the rocks along the course of the stream from Carlops down to the junction of Nine Mile Burn, a distance of a mile and a half. The following is a section extending as far as Newhall, about three-fourths of the distance.

Fig. 62.



c, Carlops village.

T, The trap bed already described.

L, The coral limestone where first seen, at the old bridge.

m, The same limestone dipping S.W. at 20°, accompanied with sandstone and shale.

n, The same limestone dipping S.E. at 30°. The burn runs 200 yards on the edges of its strata; and its various corallines and shells are well exposed.*

o, A bed of blue slate clay fifty feet deep; at the water side, where it is moist, it is plastic, and soft as cheese. I consider this the same bed with *b* in the diagram, page 153, seen in Nine Mile Burn.

p, The rough soft thick-bedded sandstone. It covers the blue shale, dipping like it S.E. at 25°; but on the opposite side of the water, about 100 feet distant, it assumes its more usual horizontal position, and forms an escarpment of forty feet, at the bottom of which is an artificial cave. It is seen every where to the eastward as we descend the stream.

From *n* to *o*, is about 150 yards along the river. The beds consist of various sandstones, compacter and in thinner strata than *p*, intermixed with black and grey shales, and dipping S.E. at 35°. Their aggregate thickness may be about 200 feet.

I have gone into these rather tedious details with the view of explaining the general conclusions I have formed as to the relations of the upper and lower sandstones, and which will be understood from the following imaginary section from Carlops eastward to Pennicuick.

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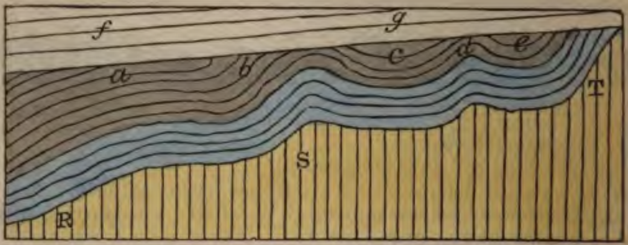
* The carboniferous limestone is much contorted in England.—See Professor Sedgwick's Paper, in Part I. Vol. IV. of Geological Transactions, New Series.

FIG. 63.



R, S, T, The vertical slate of the hills, which, to avoid embarrassment by introducing too many objects, I have here supposed to lie under the coal measures, without intervening beds of trap or conglomerate.

a, b, c, d, e, The coal measures, including the calciferous sandstones.

f, g, The upper thick-bedded sandstones.

We have seen that the beds *a, b, c, d, e,* are sometimes found on edge, sometimes horizontal, sometimes in intermediate positions, and dipping to various points.* I take for granted that they have been bent and contorted in this manner by irregular movements from below in the older vertical rocks, R, S, T, or by masses of trap ejected through these. Independently of the protrusion of the mass of the Pentlands, which would tilt the strata at their sides, the innumerable faults in the coal-field, which raise or depress portions of the beds many hundred feet, show that the disturbing agency has not been confined to the hills. For the sake of simplicity, I have not introduced any faults, though some of the contortions observed are undoubtedly due to them.

Now, after the strata were thus bent and dislocated, let us suppose a denuding current to sweep away the higher and more exposed parts of the Coal Measures. The strata would thin off, and disappear at the upper end of the basin. This they actually do at Carlops, where the coral limestone comes to the surface, proceeding round by Magbiehill to the south, and cutting off the workable coal entirely. Upon the new upper surface, *a, b, c, d, e,* thus formed by denudation, let us suppose the Roslyn or thick-bedded sandstone, *f, g,* to be deposited. It is evident that at *a* and *c,* we would find the upper sandstone resting conformably on the coal strata, while at *b* and *d,* we would find it covering their edges. From R to *a,* we would have a coal-field of vast depth, as at

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* The contortions of the coal strata follow those of the carboniferous limestone. Abundant examples of both may be found in Delabeche's "Sections and Views, illustrative of Geological Phenomena." See in particular, plate 12.

Gilmerton; and at T *e*, a limited and shallow one as at Carlops. The upper portion of this newer sandstone, again, may contain beds of coal as at Edmonstone, and part of it may in its turn have been swept away by denuding currents. This hypothesis is proposed to explain the discordant relations of the upper and lower rocks, which are sometimes conformably placed, sometimes unconformably. I am not so confident as to say, however, that it will prove a key to every anomaly which the enquirer may meet with.*

It is not assumed that the disturbing action ceased at an epoch anterior to the deposition of the upper sandstone. On the contrary, there is no doubt that it continued long afterwards, and that these beds have undergone fractures and dislocations like the older strata, though to a smaller extent. The upper beds are represented as level in the diagram for the sake of simplicity.

Dr Hibbert thinks that this Roslyn sandstone has been thrown up from below by a shift or dislocation of the strata.† He rests this idea chiefly on the fact, that, when found in contact with the other strata, it is never seen covering them, but always placed side by side with them. Much as I respect his authority, I dissent from his view of the subject, but admit that my conclusion is open to doubt.

THE KAIM VALLEY.

A valley of a singular kind begins at the village of Carlops, and extends westward along the foot of Mount Maw. It is a trough, nearly straight, about two miles long; its breadth probably averages one hundred and fifty yards; and its depth varies from thirty yards to one hundred and thirty. Its direction is N.E. and S.W., and its bottom forms every where a marsh or wet meadow. A sharp ridge or "Kaim" about sixty feet high, extends for half a mile along the middle of this valley at its east end; it is broken into separate parts by several transverse openings. The following is a topographical sketch of the east end of the trough.

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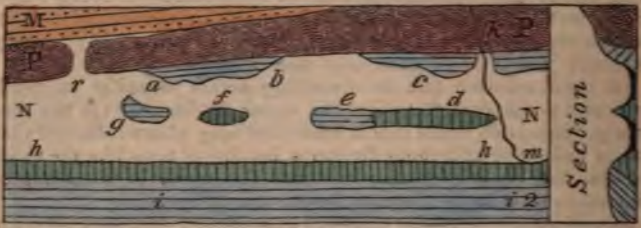
* Mr Murcheson has found a "newer coal" at Shrewsbury, lying above the older coal or coal measures, and passing upwards into the new red sandstone. For the lower beds of this new red sandstone, he has proposed the name of the "Roslyn Sandstone," and I have adopted it on his authority. The sandstone is sometimes conformable in position with the coal measures, sometimes discordant.—See Philosoph. Mag. April 1835, May 1835, and Dec. 1836. See also Mr Sedgwick's paper on the "General Structure of the Cumbrian Mountains," Geol. Trans. Second Series, Vol. IV., p. 58. He makes the same remark, that the position of the newer sandstone is sometimes conformable to the coal measures, sometimes discordant,

† Dr Hibbert informed me, that horizontal beds of sandstone are seen in juxtaposition with highly inclined beds on Bilston Burn, and upon the appearance of these I believe his opinion chiefly rests. I visited Bilston Burn in consequence of this information; but not going armed with passes from Sir F. W. Drummond and Mr Mercer, I could not get admission to the enclosed grounds. I examined, however, about two-thirds of the course of the stream from the Pennicuick road, where the rocks first become visible, to its junction with the Esk. I did not see the middle portion, where the horizontal beds probably occur; but I saw the two extremities, and from these I am rather disposed to draw an inference in favour of my own opinion.

FIG. 64.



M, The conglomerate at the foot of the southern declivity of Mount Maw.

P P, A reddish felspar porphyry. At *k* it is an amygdaloid, containing calcareous spar in its cavities. At the small cross ravine *r*, it is about three hundred feet broad.*

N N, The eastern portion of the trough-shaped valley, with the kaim, or sharp ridge *d, e, f, g,* in the middle of it.

a, b, c, Portions of a large-grained reddish sandstone, adhering to the porphyry. They dip at a high angle to the N. or N.W., not away from, but in towards, the hill.

d, f, Sharp ridges of dark porphyritic greenstone, containing grains of olivine, and black crystals of augite. It is beautifully veined with quartz and other siliceous minerals at some places. It is translucent at the edges; *d* is fully one hundred feet high; *g* is about sixty.

e, g, Portions of the same ridge, composed of conglomerate and sandstone; *g* is about one hundred feet high.

There is another part of this ridge east of the brook, *k, m.* It is a pyramid of greenstone sixty feet high.

h, h, The southern boundary of the trough, consisting of a greenstone similar to *d, f.* It is not quite so straight as here represented, and very little of it is seen.

i, i^2, Beds of conglomerate passing into a pebbly sandstone, resting upon the greenstone *h, h.*

k, m, A rivulet. *k* marks the position of the waterfall, which has cut its way back to the porphyry.

At the waterfall *k,* we find the porphyry in contact with the sandstone; and the passage cut by the stream here, exhibits some very interesting phenomena. The following is a section S.E. and N.W.

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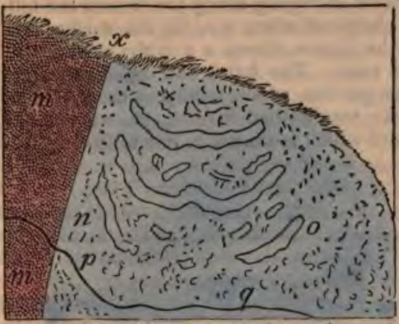
* At some parts this porphyry very closely resembles the granular conglomerate, so as to suggest the idea of its being merely the outer portion of this rock converted into porphyry by contact with the greenstone. In Logan House Glen some of the porphyries look like metamorphic sandstones or fine tuffs. Professor Keilhau thinks that many porphyries have this origin.—*Edinburgh Philosophical Journal, October* 1838.

FIG. 65.



m, m, The porphyry marked P P in the miniature map, is terminated by a plane *x*, nearly vertical, indicating a fault.

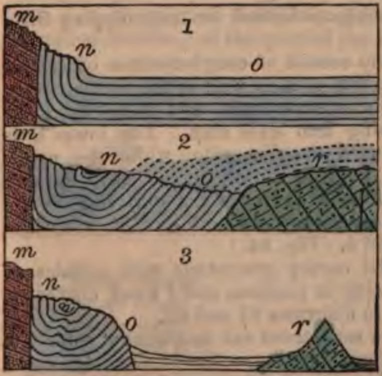
n, o, Beds of sandstone curiously contorted. From *n* to *o* may be sixty or seventy feet. The sandstone is various; red, or grey, or white, and contains angular fragments of considerable size. It is very hard, and consists chiefly of quartz, or of other substances united by a quartzy cement.

p, The waterfall.

q. The stream below it.

The following hypothetical explanation of the phenomena is offered:—

FIG. 66.



The compartments 1, 2, 3, represent the sandstone in the successive positions I suppose it to have assumed, in consequence of being disturbed by the porphyry, *m, m,* and the greenstone, and afterwards affected by diluvial action.

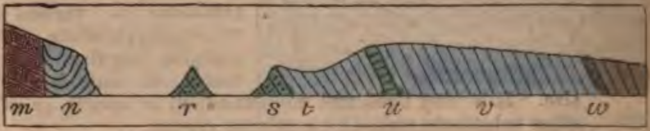
Fig. 1. Let us suppose the porphyry *m* to have risen perpendicularly upwards, fracturing the sandstone *n o,* and turning up some yards of the part at *n* nearest to it.

Fig. 2. After this the greenstone *r* (which probably forms one great bed) ascended, pushing up the sandstone *o,* which is fractured, and bent over it. The portion betwixt *r* and *n,* raised to an angle of

40° or 50°, rests, as it were, on its ends against *m*; and the original inflection of the beds at *x*, which was perhaps small, might thus come to be considerably increased, and an opposite inflection is generated in the parts farther back from the fissure.

Fig. 3. These changes took place under water; and strong currents afterwards from the west, sweeping along the foot of the hill, tore off and dispersed the shattered strata *n o*, till the surface was worn down, as shown in the figure, where *n o* is the remnant of the sandstone, and *r* of the trap. The latter now appears parted into two beds, because the portion which connects them is concealed. The various rocks would then assume the appearance which they now exhibit, and which is shown in the following section across the valley:—

FIG. 67.



m, The porphyry at the waterfall.

n, The portion of bent sandstone adhering to it.

r, The "Kaim" or sharp ridge of trap, with a marsh on each side of it.

s, The second trap, probably united under the surface with the first.

t, Conglomerates and sandstones behind the trap, dipping S.E. at 40° to 60°.

The beds nearest the trap consist of conglomerates of Mount Maw, as may be seen about half a mile west of the rivulet, *h*, *m*. They are succeeded by pebbly sandstones, and these by grey and yellow sandstones, passing into slate clay. The lower beds adhering to the hill, are also conglomerate, while the upper are sandstone. It must be kept in mind that the beds have an eastern inclination, so that the lower ones are only seen to the westward, about *i* on the one side, and *a b* on the other, while the newer ones are seen at *i*2 and *k*, (Fig. 64.)

u, A bed of amygdaloidal earthy greenstone with nodules of calcareous spar, agreeing in position, and I think character, with the bed noticed in diagrams 61 and 62.

v, The yellow fine-grained sandstones can be traced at some few localities southward from *t*. The tender black shales found along with them in the water course, east of the trap, are, as might be expected, not visible.

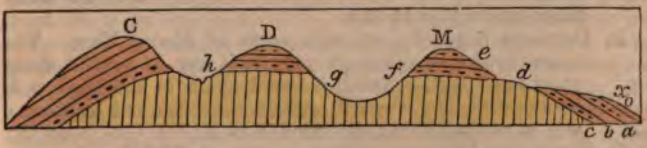
w, At three furlongs south from Carlops, we come to the coral limestone, in a quarry where it is now worked. About twenty-five feet of depth is visible, the upper portion shaly, the lower blue or grey, and abounding in encrinites. It dips S. about 25°. In an old quarry, 100 yards east from this, it is seen again, dipping S.W. at 40°. These quarries are fully half a mile S.W. from the old bridge, (see p. 157,) where this limestone was found in a vertical position. It is worked again at a rivulet about half a mile southward; again, about one mile farther south; and, again, near Magbiehill, which is three miles S.S.E. from Carlops. In the latter it is nearly level. These are the western outcrop and extreme limits of this rock, I believe, on the south side of Pentland Hills.

Coal is or was worked about three quarters of a mile east from Carlops, and I was told by some of the labourers at the lime quarry, that coal is also found below the limestone; but as usual it is not in such quantity as to repay the cost of extracting. There is a bed of fine white sandstone above the limestone, about one mile south from Carlops. It is extensively quarried. And at Whitefield, a little farther west, beyond the outcrop of the limestone, there is a bed of greenstone.

A thick bed of greenstone, having much the aspect of a clinkstone, is quarried in Carlops village; it exhibits some appearance of being in beds dipping S.E. There is a knoll, covered with grass, almost in contact with it on the south, which consists of the same species of rock. I consider these as the continuation of the traps found in the middle and at the south side of the trough-shaped valley, and represented in diagrams 64, 66, 67.

Mount Maw and Deerhoperig.—A section from Carlops, in a north-west direction to East Cairn Hill, affords a good idea of the geological structure of this part of the Pentlands.

FIG. 68.



x, Carlops village.
M, Mount Maw.
D, Deerhoperig.
C, East Cairn Hill.

Beginning at Carlops, we have the rocks in the following order:

1. A thick bed of granular conglomerate, of a greenish-grey colour, *a*. It is in strata, and dips E.S.E. at 40°.
2. A bed of rolled conglomerate *b*, of which two-thirds consist of

flattened globes, and one-third of paste. It extends along Fairliehope Burn; dips E.S.E. at 20° or 25°, and, judging from its superficial extent, may be about sixty yards in thickness. It envelopes (as often happens) small beds of the granular base, from an inch to three or four feet thick, which, in extending laterally, thin off and disappear.

3. To this succeed (in Fairliehope Burn) various alternations of the rolled and granular conglomerate *c*, in which the transition from the one to the other may be seen in all its stages. Here we have the compact greenish-grey base; there it becomes a coarse slate, in laminæ a quarter or half an inch thick: here we see a few embedded pebbles like beans; there the nodules multiply and increase in size, till it passes into a conglomerate of large rounded bowls.
4. About a furlong above the fork, clayslate, *d*, appears at the surface, both in the rivulet and on the rocky scarp to the eastward. It is reddish-coloured, soft, sectile, and nearly vertical; direction N.N.E.; and it contains beds of greywacké. These are seen in the burn for thirty or forty yards, and are succeeded by,
5. Rolled conglomerate, *e*, in beds dipping E.S.E. at a low angle, which continue to the summit of the hill. It is worthy of notice, that the embedded masses increase in size as we ascend, and some may be seen of two feet diameter. The summit is covered with turf; but every loose stone met with is a rounded nodule, and sufficiently indicates the existence of the conglomorate below. This rock is found here about 700 or 800 feet above Carlops, and nearly 1700 feet above the sea.
6. About 150 feet under the summit on the north side, we find the vertical slate again at *f*, in a small rivulet, showing that it extends under the conglomerate, and constitutes the base of the hill. It may be traced down to Lyne Water, but sometimes interrupted by soil.

D, Deerhope Rig, fully one mile north of Mount Maw. The coarse brown or yellow greywacké is seen in vertical strata at its south foot, *g*, and it is found again in the burn at *h*, on its north side, where it presents itself as a red sandstone, also in vertical strata, direction N.N.E.

C, East Cairn Hill, the southern portion of which has the name of Harper's Rig. A little above *e*, the reddish sandstone of Harper's Rig is seen protruding through the heather at some places, dipping at a low angle to the N. or N.W.

Deerhope Rig is coated with turf on the top; but the number of loose globular masses seen at *h*, leave no doubt that it is covered by conglomerate. The existenee of conglomerate under the sandstone of East Cairn Hill, is merely inferred from analogy.

I now return to the General Section, No. X. Its southern termination is at Carlops village; it skirts Turnip Hill, crosses the east branch of Lyne Water, about a mile and a half north of Cairn Muir, and proceeds onward to West Cairn Hill.

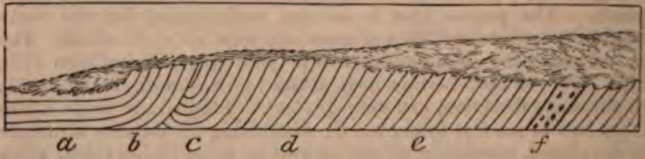
1. Turnip Hill and Mount Maw consist of beds of granular and rolled conglomerate, as already described. I traced them in the burn on the west side of Turnip Hill, as well as in Fairliehope Burn, which is on its east side, and I found the conglomerate in a quarry near the point where the one hill joins the other. The vertical slate probably exists at no great depth below, but it does not seem to reach the surface here. It joins the conglomerate in a burn which flows down to Lyne Water from Mount Maw, about a mile north of Cairn Muir, and half a mile south of the line of section. Two burns fall in at this place, and the one to which I allude, the northern, flows on the line of junction. In the southern we find the conglomerate, and near its mouth a bed of greenstone, *c*. The vertical slate in laminæ, from half an inch to two feet in thickness, continues for a mile in Lyne Water beyond the junction of these burns, as already noticed. Its direction is N.N.E., and so constant, that a traveller might steer his course by it. Portions of a coarse pebbly sandstone may be seen near the junction of the two burns, which are probably fragments of a deposit belonging to the sandstone of the Cairn Hills. The vertical slate may be traced a little farther in a branch burn, (6, in the map,) which flows from Caldstane Slap, after which we find beds of conglomerate, *e*, for the space of a furlong; the dip is not distinctly seen, but probably corresponds with that of Cairn Hill sandstone. In a minute rivulet flowing from the west into the burn marked 6, the junction between the conglomerate and the sandstone takes place. The precise spot is covered with gravel, but the rocks may be traced to within a quarter of a mile of each other. The sandstone at the end of a southern projection of West Cairn Hill, dips N.W. at 20°. Other beds to the northward dip at 20 or 25°, in the same direction, and very distinct. They are in large tables from two to six feet thick, but on weathering an interior structure is developed, consisting of laminæ two or three inches thick, often arranged diagonally. Some of the sandstone is yellow; but the more common colour is a light red, and it is generally soft. In specimens which I have examined, there seemed to be one part of felspar or clay to three or four of quartz. In the external parts the softer grains weather out, leaving the quartz, and giving it a cellular texture. The north front of both Cairn Hills is very steep, descending probably eight hundred or nine hundred feet by a single unbroken declivity; and I have no doubt that some of the strata present their truncated edges, *f*, on this side as well as the other. Assuming that the strata have a N.W. dip throughout of 20°, the absolute thickness of the sandstone must be nearly three thousand feet, for it extends over a horizontal space of 1¾ mile. I have not seen the smallest portion of shale in it; if there be any, it is trifling in quantity. It seems equally destitute of impressions of plants.

SECTION, No. XI.

THIS section extends from Linton north-westward, through West Cairn Hill, Ackinoon, and Corston Hills, to the neighbourhood of Mid-Calder. Its length is about eight miles. The height is too great in proportion.

Beginning at the south end, we find at Linton a series of beds which lose themselves a little below the village under the large masses of gravel abounding in the vicinity. These beds consist of a common sandstone, which becomes yellow coloured and fine-grained, and passes into a calcareous claystone. It seems to consist of clay or felspar powder, combined with lime. For 200 yards above the bridge it is in horizontal strata, seldom exceeding two feet in thickness. Here it changes suddenly, dips to the S.S.W. at angles varying from 20° to 30°, and maintains this dip for fully a quarter of a mile. The rock is beautifully displayed in the ravine at Lyndale, which is 150 or 200 feet deep. There are two gorges in it where it is contracted to a very narrow space; at the upper gorge the claystone assumes a coarser texture, and a brownish light-grey colour, passing gradually into granular conglomerate. The latter appears in rolled masses at the dam-head a little above Lyndale bridge. The following is a section along the course of the river :—

FIG. 69.



a, The horizontal yellow calcareous rock.
b, The inclined strata, chiefly of calcareous claystone. Some consist of claystone tuff.
c, The lower gorge—the same rocks, exhibiting contorted strata.
d, The upper gorge, where granular conglomerate begins to appear, intermixed with the claystone.
e, The conglomerate here includes a few large nodules.
f, The first bed of rolled conglomerate, containing rounded masses six or eight inches in diameter.

The inclined beds from *b* to *f* extend over a space of fifteen hundred feet; the dip is S.S.W., or nearly S., and about 25°; the thickness will be from eight hundred to one thousand feet.

The beds from *a* to *d* have exactly the texture of the claystones found in Logan House valley, and ought to be igneous rocks. I am strongly inclined, however, to consider them sedimentary, probably altered by heat, for the following reasons:—

1. They are throughout regularly stratified, and this stratification is sometimes accompanied with a change of colour, a red stratum following a grey one, showing that the divisions are not concretionary.

2. They seem to graduate into undoubted sandstones both above and below.

3. They contain interstratified beds of compact limestone, from one to two feet thick.

4. They contain also interstratified beds of claystone tuff, of a fine grain, the sedimentary origin of which cannot be doubted.

5. Beds of undoubted sandstone of the same yellow colour, and very fine-grained, extend eastward from this deposit to Carlops, and precisely in the line of their prolongation. To me it seems probable, on these grounds, that they consist of the detritus of claystones and felspars united by lime, of which they contain a large proportion, and that they are analogous to the fine tuffs interstratified with them. Brongniart is disposed to assign a sedimentary origin to the claystones generally.—(*Classification des Roches*, p. 113.)

From *b* to *f there are eight or ten beds of limestone*, from four inches to two or three feet in thickness. Some of them are of a brownish-white colour, with a splintery fracture, and very hard; some of the more usual grey colour; some reddish-brown; the thinner beds, from the upper gorge to the dam-head, have the appearance of strings of lenticular masses, like those of clay ironstone. To the lime in these beds must be added that existing in the claystone and the yellow calcareous rock, and even in the base of the conglomerate *f*, parts of which effervesce with acids. This series of rocks, in short, is characterised by the abundant presence of lime, and it contains lead glance. The black shale and coal constituting the upper portion of the group, is not visible here, owing to the covering of gravel, which commences at Linton village and extends southward; but it is seen in the burn at Carlops, as described in last section.

Some of the yellow beds are similar to those seen below the black shale at Carlops, and a few of them agree also with the latter in not effervescing with acids. The pebbly beds, from the upper gorge to the dam-head on the other hand, correspond sufficiently with those exposed on the south side of the trough valley, described page 158. In the two together, we have the series from the coral limestone to the conglomerate or old red sandstone completed.

Grains of copper pyrites occur in the yellow sandstone at Lyndale. Lead glance is found also in strings, or crystals; and to such an extent, that it was formerly worked, about half a mile eastward, near the old road. A little silver was combined with it.

From Lyndale, along the burn, following the east branch by Cairn Muir to the point 6 in the map, where the vertical slate first appears, we have four large beds of rolled conglomerate, divided by as many of the granular base. The direct distance exceeds two miles; but measured right across the strata, it will be about eight thousand feet. The dip varies much, being occasionally S.E., S.W., and to all intermediate points; it probably averages 10° or 12°; and the true aggregate thickness of the beds may be about one thousand two hundred feet, of which the rolled conglomerate perhaps constitutes one-fourth, and the granular rock three-fourths. The first rolled bed is at Lyndale dam-head; the second at Stoneypath; the third at Cairn Muir; and the fourth at the point where the vertical slate appears. A deposit of rolled conglomerate often contains tabular masses of the granular kind within it, from a foot thick to three yards, but, for the sake of convenience, it is still considered as one bed. On the other hand, a deposit of the granular kind is described as one bed, though small layers of rolled pebbles may appear in it here and there. The rolled conglomerates are precisely similar to the bed at Habbie's How. The masses are of all sizes up to eighteen inches in diameter; they are generally well rounded and smoothed; of a flattened spheroidal rather than a globular shape; and, in nine cases out of ten, reposing on their sides; nineteen-twentieths of the whole are of the same substance with the paste or base; but a few travelled fragments of felspar, quartz, porphyry, and even syenite, may be seen among them. The rolled pieces compose generally three-fourths of the mass, the portion of finer matter mixed with them, being merely sufficient to serve as a cement. The granular beds are sometimes in strata two, three, or more feet thick; sometimes they are slaty, and perfectly similar in appearance and composition to the coarser vertical beds, or greywacké, on the edges of which they rest. I found one bed of greenstone in Lyne water, near Stoneypath, but of small size. It is not marked in the map.

The line of the General Section, however, differs from that just described. It passes along the west branch of Lyne water, which I shall call Badingill Burn. The dip here is very regularly to S.S.W., about 15° or 20°, so that the burn cuts the beds obliquely, and sometimes runs on their edges. About a mile from the fork of the two streams, near a hut erected for the use of the men who quarry Mr Ferrier's limestone, we find a soft, red, striped sandstone in beds, dipping N.W. at 35°, (*c* in the section.) Probably a hundred yards of turf and gravel intervene between this and the nearest visible part of the conglomerate. The sandstone has been quarried, and its position is quite distinct. About half a mile to the northward, at a projecting ridge of West Cairn Hill, large thick beds of the sandstone stand through the heather, with the same dip. In a small rivulet (at 3 in the map of the hills) which flows into the Badingill Burn from the south-west, I found beds of a kind intermediate between the granular conglomerate and an ordinary sandstone, and with them two beds of blue compact limestone, about eighteen inches thick, and in small angular concretions. About two furlongs farther south, I found a bed of the conglomerate, with an apparent dip to N.N.W. On the east side of Badingill Burn, about a quarter of a mile from the sandstone, limestone is quarried by Mr Ferrier, the proprietor. It is a bed about five or six feet thick, hard, reddish-coloured, with a splintery fracture. It closely resembles the limestone found at Bevelaw, and in the burn above Habbie's How. The bed rests on a grey sandstone faintly striped with red, and dips N.W. at 30°. It is at the north side of the hill called Mickle Knock, which consists of conglomerate.

From these facts, and from the position of the conglomerate in Caldstane Slap Burn, formerly described, I infer—1, that the conglomerate assumes a north-west dip at the north side of Mickle Knock, and bends under the sandstone of Cairn Hill, as shown in the large section; 2, I think it probable, that the conglomerate at its junction with the sandstone, is either interstratified with it, as in the burn above Habbie's How, or passes into it by a gradual transition as at Lyndale; 3, I assume the existence of the vertical slate under it here, as marked in the section, because I find the slate exposed within three quarters of a mile to the eastward.

In West Water, which runs parallel to Lyne Burn and Badingill Burn, about a mile and a half westward, we find alternating beds of granular and rolled conglomerate till we reach a point about two miles beyond North Slipperfield, where sandstone occurs; but the junction of the two rocks is not visible.

At the north foot of West Cairn Hill, in the burn which flows down to Harper's Ferry, we find various strata of sandstone, with some shale, and a little limestone, in beds dipping S.E. at 25°. The sandstone contains impressions of plants. A furlong west of the Inn at Causeyend, a bed of coal three feet thick crops out with a dip to the south, which dip continues to the Water of Leith. In Colzium grounds the rock was bored some years ago to the depth of forty fathoms, and several seams of coal found, but too thin for profitable working. The dip is very irregular, owing to a whin dyke which crosses the burn near Colzium House.*

About a mile and a half from the foot of West Cairn Hill, a bed of trap occurs at Achinoon.—(See the General Section.) A very little beyond this, we find, in a quarry at the road-side, a greenstone of a very singular kind, the upper surface of which dips south at 15°.† (It is marked *f* in the section.) No sandstone is seen here, but it is found about half a mile eastward, dipping S.E. at a low angle, with numerous carbonaceous impressions of plants. At Corston Farm, *g*, about one mile north of Achinoon Hill, a bed of trap, probably 100 feet thick, crops out with an apparent dip to south. I need not repeat here, that the dip of a bed of trap in general merely marks the inclination of the beds of the sedimentary rocks amongst which it lies. At Red Craig, about another mile farther north, there is a large sandstone quarry, in which the beds dip S.S.W. at 20°. It seems to be covered by trap a little to the southward, but I only saw the superjacent rock from a distance. From these facts, I infer that the rocks from the foot of the Cairn Hills to the vicinity of Mid-Calder, have the southern inclination assigned to them in the Section. To render this inference secure, however, a more careful examination is necessary.

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* For these facts I am indebted to Mr Geddes, mining engineer.

† This rock offers to the eye the appearance of a confused assemblage of fragments of clayslate, from the size of a pin-head to that of a small bean, intermixed with

Dalmahoy Crags.—These two bold and picturesque Crags are about eight hundred feet in height above the sea, according to Professor Forbes.

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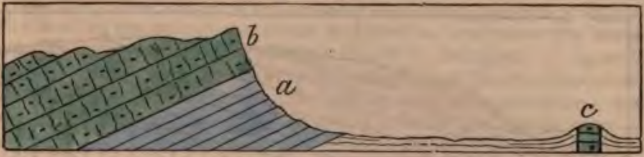
crystals of a black shining substance, and grains or crystals of a greyish-white colour. The one is probably augite, the other felspar. The clayslate is sectile, and constitutes more than half the substance of the rock. I took it for what Dr Macculloch calls a "porphyritic greywacké," and considers as a changed clayslate. Two friends to whom I showed it, formed the same opinion. It has been pronounced a greenstone, however, by good mineralogists, and this is no doubt the more correct designation, since the crystals have been formed in it, and are not accidentally mixed with the other material. Considered in this point of view, the rock is interesting as exemplifying the process by which some varieties of the trap family have been produced. The subject has not escaped the indefatigable Dr Macculloch. He observes that slate clay and shale have been converted by heat into greenstones, porphyries, hornblende schist, siliceous schists, basalt, and lydian stone.—(System of Geology, I., p. 154, 210, 231; II., p. 128, 280.) This, he says, "is clearly proved by finding trap and porphyry entangling fragments or schists, in which the gradual melting down of the material is distinctly traced." Again, "the most fusible material becomes converted into basalt or greenstone, or, under less heat, into siliceous schist, the argillaceous limestones into chert, and the sandstones into analogous compounds, while the infusible clays become jasper." Hence, it seems probable that in the Achinoon rock we have nature caught in the fact, as it were, or the process of converting slate clay into greenstone arrested when half completed. Nor, perhaps, have we far to seek for the agent. A bed of trap *e*, exists about a furlong southward, which in all probability once covered the quarry. If this was injected among the other rocks in a state of intense heat, and had below it a bed of slate clay, it may have produced the change now described. It is some confirmation of this idea, that while the interior displays no structure, the upper portion, to the depth of about eighteen inches, divides into very small quadrangular columns, so as to give the exterior surface the appearance of a tesselated floor. Above this again, we have a bed of fine black basalt, about four feet thick, and disposed in regular laminæ, from six to eight inches deep, which were no doubt once strata of slate clay. Both the crytalline and concretionary structure, as Dr Macculloch elsewhere remarks, might be developed without actual fusion.

FIG. 70.



Easter Dalmahoy Crag.

They consist of a large mass of trap, incumbent on sandstone.

a, The sandstone, of which a depth of one hundred feet is visible. There is very little shale in it. It dips S. or S.S.E. at 18°.

b, A dark greenstone of great depth, in apparent beds or strata. According to Boué, the base of the rock is clinkstone or felspar, and it is rendered porphyritic by the two* common varieties of felspar crystals.

c, A broad greenstone vein, running east and west, parallel to the two hills, at the distance of a quarter of a mile. It is easily distinguishable by the swell of the ground, and is noticed here from its possible connexion with the Crags.

There is another bed of trap southward. It is exposed in a small brook half a mile west from Balerno village. In the burn which flows northward from Liston Shiels, several beds of sandtone, and one of hard blue limestone are seen dipping south at 12° or 15°. This is a mile and a half south of Dalmahoy Crags. About a mile farther south we find the thick-bedded soft reddish sandstone of the Cairn Hills, commencing near Bevelaw Burn, and ascending the north slope of the Pentlands, with a dip to the N.W. of 12° or 15°. The position of the rocks at this place, which is about four miles east of the line of Section VIII., is therefore analogous to that shown in the section.

Mount Maw.—This hill, which forms a narrow ridge two miles in length from north to south, and 1700 feet in height, occupies an important place in the geology of the Pentlands. Near its north end I traced the vertical slate to a point within one hundred and fifty feet of its summit. I crossed it at a point three quarters of a mile farther south, following the beds of two streams, and the vertical slate was not found till I arrived at Lyne water. Nothing was seen but conglomerate. The same rocks are seen in Cairn Muir Burn; in Lyne water, which cuts across its south end; and at every point on its summit where the covering of turf is wanting. Below is an ideal section of the hill lengthways, from north to south, according to my conception of its structure.

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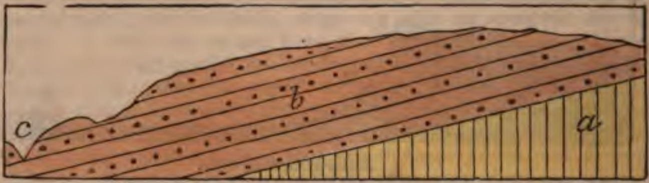
* Essai. Geol. p. 157.

Fig. 71.



a, The vertical slate, reaching nearly to the summit at the north end.

b, Beds of granular and rolled conglomerate, forming the entire mass of the hill at the middle and west end.

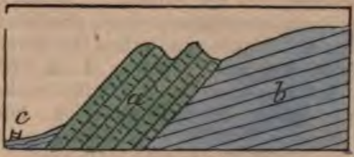
c, Lyne water near Stoneypath, at the south end of the hill.

The overlying rocks, as seen in Lyne water and its branches, dip nearly S., but sometimes S.W., that is, in the direction of the length of the hill, at angles varying from 5° to 20°; and their absolute thickness at right angles to their inclination, is probably not much short of one thousand feet. This is by far the greatest individual mass of these overlying rocks in the Pentlands.

There is another interesting feature in the structure of this hill, and its relations to the adjoining parts of the chain. While the beds on the west side dip S. or S.W., those on the east side dip S.E., or rather E.S.E., and at a higher angle. The latter is the usual inclination of the overlying beds every where to the eastward, except in a limited space at Habbie's How. The other dip, to the S. or S.W., prevails over both branches of Lyne water, from Stoneypath northward, in West water, and Medwin water, and to the westward generally, except at Mendick Hill, where the S.E. dip is again seen. In short, Mount Maw forms a sort of axis, over which the stratified rocks appear to bend. Perhaps the change may be explained in this way. Supposing the whole beds, westward as well as eastward, to have had the usual S.E. dip originally, it is plain that if an axis or stiff horizontal line, extending S.W. and N.E. at a great depth under the surface, were pushed up to a certain height, it would *invert* the dip (turn it N.W.) on the one side, and greatly increase its angle on the other. But if the lifting object extended S. and N., the deflection on the west side would be entirely westward; however far it were carried, it would not *reverse* the dip, because it could not communicate any northern deflection; its effect would, therefore, be on the one side to turn the S.E. into a S.W. dip, and to diminish its amount; and on the other to increase the dip, and turn it a point or two more to the east. Now this is the case at Mount Maw; hence it may be *inferred that* a fracture, attended with a great *lift* of the vertical slate under Mount Maw, had disturbed the strata in the manner described. The movement probably did not extend to Mendick Hill; but either this or a subordinate movement perhaps produced the bend in the calcareous strata at Lyndale, and raised the lower portion into the inclined position which it occupies. I am well aware that there are anomalies in the position of the stratified rocks here, as elsewhere, of which it is vain to seek an explanation; but still it may be admitted that there is a sufficient consistency in the phenomena described, to give probability to this conjecture.

On the more westerly part of the hills, a few remarks may suffice. The south end of Millstone Rig is of conglomerate, the north of a hard reddish sandstone, but I could not discover the junction. Near the head of Medwin water I found large beds of sandstone dipping N.W. at 10°. Among them is a stratum of reticulated sandstone, which has its surface divided into numerous small compartments, by interlacing bars of stone, resembling the carved partitions of cathedral windows. There is very little, if any shale here. In Westwater of Dunsyre, about a mile south from this, I found a firm sandstone dipping S.W. at 5°; and on a portion of it, from which the clay had been removed, there were beautiful and well marked dressings, pointing right across the stream, or E. and W. About a mile farther south towards Dunsyre Hill, there are two quarries, where the red-coloured sandstone is exposed in beds six feet thick, dipping S.W. at 10°. I did not examine the rock westward of this; but I traced Linhouse Burn from Crosswood to its source. I visited Wilsontown, and skirted the west boundary of the hills; and the inference I drew from the facts observed is, that the strata, as far as the Lanark road, consist almost entirely of a soft thick-bedded sandstone, similar to that of Cairn Hills, dipping through various points of the compass from W. to S.S.W., but most generally to W.S.W., and at a low angle, probably averaging 7° or 8°. Medwin Burn, Westwater of Dunsyre, and even the upper part of Linhouse Burn, all run on the edges of the strata. I saw no perfect shale, and no impressions of plants till I came very near to Crosswood House, where they are seen in abundance, and where a bed of bluish-coloured sandstone is found in very regular small columns, lining the water course like a carefully laid pavement. A bed of trap is exposed in the stream a little eastward, and may account for the columnar structure. This bed or vein of trap (coloured green in the map,) is, perhaps, a continuation of that which is found at Colzium, two miles eastward. Though the beds of sandstone, without carbonaceous impressions, extend over a horizontal space of three miles, they are probably not thicker, owing to their low inclination, than those of West Cairn Hill.

FIG. 72.



a, The picturesque crag above Dunsyre, consisting of trap. I neglected to note the kind, but I think it is a porphyritic basalt, like that on the S.E. limb of Arthur's Seat. It presents an appearance of beds, dipping S.E. at 25°, with small transverse prisms. The crag is probably five or six hundred feet above the plain on its south side.

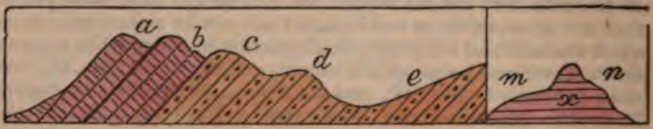
b, The thick-bedded sandstone, dipping S.W. at a low angle, and presenting its truncated ends to the trap.

c, Dunsyre village.

On the west side a portion of traptuff is seen between the sandstone and the basalt. The hill has on its east side twenty or thirty of those terraces, called *daces*, of which we have examples on the south-east part of Arthur's Seat. The one end of each terrace here is fifty feet or more lower than the other, showing that they could not be produced by water, as some have imagined, like the parallel roads of Glenroy. They are unquestionably artificial. "Terrace Hill," at Newlands, four miles eastward, exhibits similar works.

FIG. 73.

SECTION N.W. THROUGH MENDICK HILL.



a, Beds of clinkstone and clinkstone porphyry, generally with a red base, some spotted with white felspar, some striped, seen at its south base, its summit, and in Westwater.

b, Reddish-grey porphyry, also of a slaty structure; it projects beyond the first bed, producing a sort of platform on the north side of the summit, and leaving a hollow of one hundred feet.

c, A brownish granular conglomerate seen in Westwater, and on the hill, forming a second platform.

d, Conglomerate, with rounded bowls extending to one foot in diameter, forming a third platform.

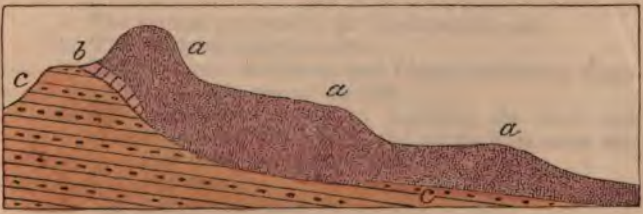
e, Compact conglomerate of a reddish-grey colour, seen in Westwater, and partly on Millstone Rig, *e*. My belief is, that *this* conglomerate passes under the sandstone which forms the north part of Millstone Rig; but I could not find the junction of the rocks any where.

Mendick Hill, which is one mile west of Linton, is steep and isolated. Its height in Knox's map is said to be 1350 feet; but I think it cannot be under 1500, if the estimated heights of some of the neighbouring hills are correct.

There is a long narrow wooded hill, called Magbiehill, one mile south of Linton, rising probably three hundred feet above its base. The rock consists of a firm sandstone, in thick strata dipping S.E. at 30° or 35°. It is rather fine-grained, of a deep red colour, with numerous purple spots, and some scales of mica. It is much iron-shot, seems to contain very little quartz, and is quite unlike the sandstone of Cairn Hill. At the east end of this hill, about one mile north of Noblehouse, the coral limestone crops out. The covering of gravel and soil round the skirts of the hill, renders it difficult to ascertain its relations to the rocks in the neighbourhood. It appears probable that it is a fragment of the vast mass of sandstone which wraps round the west end of the Pentland Hills, and which had originally extended along at least a part of the south side also; and that its position in the series of rocks is above the calcareous sandstones seen at Linton, and below the coral limestone.

Roberton Hill, about a mile south from Dunsyre, consists chiefly of clinkstone; and rocks of the same class, including quartziferous amygdaloids, continue with some interruptions to Tintock. We have thus a series of porphyries extending over a space of thirty-five miles, reckoning from Braid Hills. I visited Tintock in 1837, and, from a hasty examination, inferred that its structure was as follows:—

FIG. 74.



a, a, a, Flesh-coloured felspar, identical with that of North Black Hill. It seems to cover all the upper part of Tintock. It contains veins of sulphate of baryta.

b, A dark-grey clinkstone at Pap Crag, into which the felspar passes by a gradual change.

c, c, Beds of conglomerate, ascending within 400 feet of the summit, and found at various places along the south skirts of the hill. It is probably 1000 feet in depth. Below Pap Crag it consists of rounded masses often as large as the head. Many of these consist of travelled stones, such as quartz rock; and in this respect it differs from the conglomerate of the Pentlands. At Wolf Bridge, which crosses the Clyde, it is a very hard compact rock, scarcely distinguishable from a compact greenstone; and hence has been named by Dr Macknight " the greenstone substance." *—The height of Tintock above the sea is 2300 feet.

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* Wernerian Transactions, Vol. II. p. 123.

THEORY OF THE HILLS.

So many facts are yet unknown to us, and so many of the agents by which Nature has worked mighty changes, are still wrapped in mystery, that geologists, though able to explain no inconsiderable number of phenomena, daily meet with others which baffle their utmost sagacity. Those problems still to be solved—those effects for which they are yet unable to assign causes—offer prizes to active intellects, and increase the attractions of the science, while they are proofs of its imperfection. They are not arguments against speculation; for the labour of collecting facts would be dry beyond endurance, if separated from the study of causes; but they ought to teach us diffidence in all our conclusions which go beyond the most simple and direct inferences from well-ascertained facts. Geological theories must, for the present, involve many uncertain elements, and should be considered as provisional, at least in many points. The following hypothetical remarks are therefore proposed merely as conjectures; and I shall be ready to renounce any, or all of them, when a better explanation of the phenomena is presented.

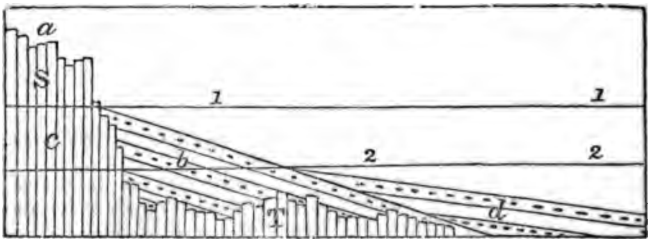
In the west end of the hills, where we have the suite of rocks best displayed, the order of superposition if the whole were placed horizontallv above each other, and beginning at the bottom, is as follows:—

1. The vertical greywacké, the fundamental rock.
2. The overlying conglomerate.
3. The claystone, clinkstone, and felspar porphyries, found on the south side of the hills.
4. The calciferous sandstones, including the thick red sandstone of Cairn Hills, and all the beds under the upper thick bed of limestone.
5. The coal measures.
6. The Roslyn sandstones.

1. *The Vertical Greywacké.*—Not to involve myself in too wide a range of discussion, I pass over what regards this rock, with the single remark, that it must have been originally formed in horizontal beds, like sandstone, and afterwards turned up into the position in which we find it, by causes which it is foreign to my present purpose to inquire into.

2. *The overlying conglomerate* consists merely of the *detritus*, or of rolled fragments, of the vertical strata, on the ends of which it rests, with a mixture of foreign substances, such as quartz, felspar, and limestone. It is evidently the product of aqueous agency. When the greywacké was turned up into its present position, with rolling waters playing over its edges, since some of the strata are thick, some thin, some firm, others feebly coherent, we may suppose that the exposed parts of the looser strata would be worn down to clay or sand, and the harder broken into fragments, which would be smoothed and rounded by long agitation in the water. The sand would concrete into beds of fine-grained, the rolled pieces into beds of coarse, conglomerate. As the first action of the water would be exerted on the projecting parts of the vertical strata, the *detritus* would be deposited in hollows, or on the sheltered side of prominent firm rocks, exposed to currents. In the western parts of the Pentlands, where the structure and position of the overlying conglomerate is best seen, the great mass of these rocks is on the south side of the hills. On the north side (head of Lyne Water) they thin off and disappear, and the vertical slate presents itself. In Mount Maw they are probably eight hundred feet thick,* and the conglomerate at the top of that hill, must be the wrecks of a rock which then occupied a higher situation. But it is farther worthy of notice, that much of the coarse overlying conglomerate seems to consist of portions of the finer beds of the same, torn up after being consolidated, and worn into bowls by long rolling in the water. We may explain this hypothetically.

FIG. 75.



S, T, The vertical slate in its original condition.

a, The projecting uneven ends of its strata, exposed to abrasion by currents.

b, Overlying strata of coarse and fine conglomerate, consisting of the *detritus* and *debris* of the prominent parts *a*, of the vertical strata broken off, triturated, and lodged in the hollows by tides or currents. We may suppose these inclined beds to consist of the ruins of the vertical strata *a,* worn down to the line 1, 1, by currents operating from the left.

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* At Callender and in the vicinity of Crieff, there are conglomerates of the same kind, but less argillaceous, presenting a thickness of 7000 or even 10,000 feet.

d, Let us suppose the action of the current to be continued, till the vertical strata are worn down to the line 2, 2. It is evident, that besides an additional mass *c,* of the vertical slate, the upper portion of the overlying rocks, *b,* would be in their turn swept away, and from the detritus and debris we might have a new series of beds, *d,* formed. This I think must often have been the case in the Pentlands; for while many of the conglomerate bowls consist of pieces of the firm greywacké, well rounded, others seem as plainly to be merely fragments of the recomposed overlying rocks, torn up after being deposited, and worn smooth by rolling.

Three observations present themselves with regard to the conglomerate. First, The long time which must have been required to give such perfectly rounded forms and smooth surfaces to these globes, of which there are four beds at least on Lyne Water, each sixty, eighty, or one hundred feet thick. Secondly, The collection of these rolled masses at particular spots, and in the immediate neighbourhood of the rocks from which they are derived, is scarcely compatible with the action of great currents, which would have swept away and dispersed such moveable fragments long before they were so perfectly rounded; and rather suggests the idea of tidal action, operating with its flux and reflux within hollows of limited extent. Thirdly, The alternations of coarse and fine conglomerates, probably indicate alternate periods of violent agitation, and comparative repose, in the waters. I have tried to connect the coarse conglomerates found at different spots in the basin of the Lyne, by assuming one to be the prolongation of another, but without success. They seem generally to be local, and of no great lateral extent.

The conglomerate is here described as composed solely of the detritus and debris of the greywacké and clayslate; but even those portions of it which rest immediately on the slate, contain grains and fragments of light-coloured felspar, showing that igneous rocks of this class existed here before the conglomerate was formed. The darker-coloured grains which also abound in it, may consist partly of the grey and dark-red porphyries, though these, from their resemblance to the clayslate and greywacké, are not easily recognised. At some places also there are a few travelled stones in it, namely, large fragments of quartz rock, white crystalline quartz, and others, from primary formations.

The Porphyries.—Upon the greywacké, slate, and conglomerate, which then constituted the floor or bottom of the sea, the porphyries, issuing from submarine craters or fissures, must have been deposited. That these porphyries were the product of successive eruptions, seems to be established by the following facts:—First, It is shown by the variety in their texture, colour, and composition; for it is quite inconceivable that the white felspars, blue clinkstones, and red porphyries, could be parts of one current of fused matter. Second, It is shown by the amygdaloids, which are analogous to cellular lavas. In a deep current of lava, the bottom is as compact as our basalts; the middle is slightly porous; and the top, owing to the absence of pressure, is generally full of cells. If water holding lime, silica, or alumina, in solution, stood long over such lava, these substances would pass into the cells by infiltration, and convert the upper part of the current into an amygdaloid.[*] The amygdaloids in the Pentlands were the upper part of flowing masses of submarine lava. Their repetition is evidence at once of successive eruptions, and of the presence of water at or after their deposition. Third, It is shown by the mechanical deposits intercalated among the porphyries, several of which have been mentioned, and there are unquestionably others which have escaped my notice. These are, the conglomerate covering part of North Black Hill, and which may perhaps be the same with that underlying Belld Hill and Harbour Hill, (see page 134;) the conglomerate found under Turnhouse Hill, of which that between Harbour and Belld Hill may be a part, (see page 131;) the beds of claystone tuff found at Chapel Burn, and in South Burn, (see page 139;) and the breccia found near East Side Farm, (see page 143.) The conglomerate covering part of North Black Hill, has obviously been produced by the action of water on the felspar, and on the greywacké adjoining. The claystone tuff of Chapel Burn and South Burn, has incontestably a similar origin; and the breccia near West Side Farm consists of fragments of all the porphyries below it, deposited in beds by aqueous agency. Each of these mechanical deposits is found separating one bed of porphyry from another, and proves beyond question the presence of water. The amygdaloids, as already observed, afford evidence to the same effect. We may therefore infer, that *the porphyries were not injected between or among pre-existing rocks*, like most of the traps, but deposited partly on the upturned greywacké slate, partly on the conglomerate, that is, the old red sandstone; and further, that this took place under water.

It is difficult to determine in what manner the ejection of the porphyritic masses took place. The fused matter might issue like a stream of lava from a single crater situated at one extremity of the chain, and flow in a long narrow current towards the other: or it might be thrown out from fissures running parallel to the chain, and in juxtaposition with it. Boué[*] is in favour of the former hypothesis, which seems to me most consistent with the phenomena to be explained. Let us indulge in a few conjectures.

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[*] The most compact rocks are permeable by water. "I have seen (says M. Fournet) near Pontgibaud, blocks of basalt that had lain long under water, which were so hard and tenacious that it was necessary to blast them with powder; yet their cavities were full of liquid, and had begun to coat themselves with silky needles of mesotype, which are not found in parts of the same rock that had remained dry."—Daubuisson, *Traité de Geognosie*. Tom. iii. p. 430. 1835. The matter which fills the cavities sometimes exists in solution in the water, sometimes is derived from the rock itself.—Daubuisson, *ubi supra*.

1. The crater, we may suppose, was at the east end of the chain, since the porphyries are thickest there. A long hollow or trough, some miles wide, excavated by water, or produced by subsidence, probably existed in the vertical slate, in which hollow conglomerate was forming by the action of water.

2. By successive eruptions one stream of porphyry was thrown out after another, and flowed south-westward along the cavity, the lowest bed resting on the conglomerate, or on the vertical slate, where the conglomerate happened to leave it uncovered, and the upper beds resting on the lower.[†]

3. Occasionally, in the intervals between one eruption and another, conglomerates, breccias, or tuffs, were formed by the action of water on the rocks already existing, and being covered by the more recent eruptions, now appear intercalated among the porphyries.

4. After the eruptions had ceased, oceanic tides or currents cut away the soft vertical slate on the two sides of the chain; the porphyry being incomparably firmer, resisted this destructive agency to a certain extent, and protected the slate below it; but the outer portions of its beds were broken off, and its mass worn down from the form of a long flat parallelogram, to that of a narrow ridge, with breaches in the softer parts. The state of the surface was thus reversed; what was originally a trough in the slate would now be a high ridge of porphyry, and the two plateaux of slate which formerly flanked the trough, would now be replaced by two deep cavities on the opposite sides of the porphyry ridge.[‡]

5. In these cavities beds of sandstone, slate clay, limestone, clay ironstone, and vegetable matter, were slowly deposited by water during a long course of ages, and now constitute the calciferous sandstones and coal formation.

6. After this, two great movements took place: first, either the ridge was pushed up, and tilted the sedimentary strata on its two

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[*] Boué's opinion is entitled to some weight. Having studied at Edinburgh under Professor Jameson, he is well acquainted with the rocks of this district; he has since visited the extinct volcanoes of Auvergne, the Eyfell, and Hungary; and he is, besides, an able geologist.

[†] In Iceland, a single current of lava has been found to have a length of fifty miles, and a breadth from seven to twelve.—*Lyell's Principles of Geology*, Vol. ii., p. 130.

[‡] The sharp form of the hills must have resulted chiefly from denudation, the effects of which are well exemplified in West Kipps Hill, (see page 151.) It must also be kept in mind, that sharp as the hills appear, their visible height is only about one-eighth part of their visible breadth. The influence here ascribed to the porphyry in protecting the soft slate, is analogous to that which the trap has undoubtedly exercised among the sandstones and shales of the newer formations. See pages 45 and 96.

flanks, or, what is less probable, the same effect was produced by these strata sinking down: second, by a separate movement, or perhaps a modification of the former, the northern side of the hills was elevated three thousand feet above the southern; the beds which had once been horizontal, were thrown into a position inclined at 20° or more to the south-east; and the porphyries bore up portions of the newer strata with them.

7. Many partial upheavings and subsidences followed, producing *faults* or other local alterations in the position of the sedimentary rocks, and to a smaller extent in the porphyries; while the tides and currents of the ocean continued their destructive agency, cutting away the softer rocks, undermining the harder, wearing down prominences, and smoothing the surface.

8. Lastly, some great movement or succession of movements, raised the hills and all the adjacent rocks above the sea.

Where the subject is so obscure and complicated, and the data so scanty, it would be a waste of time to enter into any elaborate defence of this hypothetical sketch. A few observations may suffice.

1. The arrangement of the porphyries in long lines, as in the Pentlands and Ochills, instead of broad extended plateaux, approximates their form to that of coulées of lava, and is in favour of the supposition that they proceeded from points or craters, and not from long fissures.[*] An examination of the district between the

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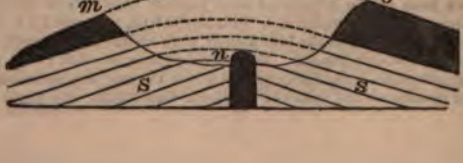
[*] It was assumed (page 100,) that the traps had been in most cases thrown up through veins or fissures. The same origin is not here ascribed to the porphyries, for two reasons. First, no veins of felspar, clinkstone, claystone, or the other characteristic rocks of the Pentlands, are seen either within the range of the hills, or on their flanks. On the contrary, all the veins found either in the hills or the adjoining districts, are of trap. Secondly, one, two, or more veins, right under the mass of the porphyries, would not explain the appearances presented. In this case the lower beds of porphyry must have been fissured again and again, to afford a passage to the fused matter which constitutes the upper ones. The fissure remaining ultimately full of the same matter, we should have had a vein corresponding to each variety of rock, and some of these veins must have been visible, whereas not one has been discovered. But though this mode of formation does not seem consistent with the position and arrangement of the porphyries, it is probably applicable to trap hills, even of large dimensions. The valley of Strathblane, about ten miles north from Glasgow, seemed to me, from a short examination some years ago, to be the seat of a great vein, through which, very probably, the trap beds of a part, at least, of the Campsie and Kilpatrick Hills were ejected. Of this valley the annexed figure is a cross section.

FIG. 76.



Grampians and the Southern Hills of Scotland does not countenance the idea, that wide extended masses of porphyry are lying unseen below the sedimentary rocks, and that the Ochills and Pentlands are mere portions of these pushed up and exposed.

2. We must assume the existence of a trough, to account for the liquid porphyry flowing only in one direction, and not spreading out in breadth, and this trough apparently must have been in the slate. The Lammermuir and Peebles-shire Hills may be considered as part of the southern flanking *plateau*, and prove that the slate was high enough to answer the purpose. The liquid matter could not be confined by the strata of the coal measures or calciferous sandstones, because, if these were being deposited at the time, beds of them should have been somewhere interstratified with the porphyries, which is not the case.

3. If the hypothesis be correct, all the variety of igneous rocks existing any where in the hills, should be found in the neighbourhood of the supposed crater, namely, at the east end. This does not hold true; yet it approximates to the truth; and it is quite possible that the portions connecting certain distant masses with the crater, may have been swept away by denuding agency.

4. It is not necessary to suppose that there was only one crater: there may have been two or three situated in a line, (for volcanoes are found to affect this linear arrangement, those of Mexico, for

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The traps on the north side of the valley *o*, are many hundred feet thick. I did not examine them on the south side at *m*; but it is evident from Dr Macculloch's geological map that they run parallel to the other, and are merely divided from them by the narrow valley. Under the trap, on both sides, there are beds of sandstone and shale, *s*, to the depth of two hundred feet, or more, which are beautifully exposed on the north side *o*, at the waterfall called the Spout of Balagan, where they dip north. Under *m*, on the south side, they dip south; but in this, as well as the other case, at a low angle, and if prolonged they would form a continuous deposit across the valley. In the middle we have three detached small hills, *n*, the western probably three miles from the eastern. I examined the one opposite the Spout of Balagan, called Dunglass Hill, which lies between the other two. It is about 150 feet high, probably 300 broad, and consists of a mass of basalt. The one westward seems rather higher; the other lying eastward is lower, but long-shaped in the direction of the valley; and I was informed, by labourers, that both were of "whinstone." Here then we have sedimentary rocks *s*, *s*, ruptured and separated, which had evidently once been united; in the hillocks *n*, we have three funnels (seated probably on one long fissure) through which the trap rose that ruptured the strata. In the large beds of trap *m*, *o*, which cap the hills, we have the matter thrown out from these funnels while the sedimentary beds yet occupied the valley, and in the opposite dip of the strata, we have the effect of the movement of elevation which attended the emission of the trap. When the fused matter pierced these beds, it would rend and shatter them, and so enable diluvial currents or similar agents to sweep the loosened portions away, and scoop out the valley. The trap of Campsie Hills here is in beds, which are generally separated by decomposed layers of the same rock, from one to four feet thick, and often soft enough to be crushed with the fingers. It rests on the lower part of the coal formation, and large veins are seen near the foot of the hills at several places. The encrinal limestone is worked at Baldorran quarry, probably three hundred feet under the lowest bed of trap. This seems to me a very interesting valley, and well worthy of a careful examination.

instance,) and throwing out similar matter, not at the same moment, but in the same geological epoch. The existence of the long line of similar porphyries extending from Kirkyetton to Tintock, may thus be accounted for. Braid Hills may be the produce of a later eruption from the eastern crater. It is probable that a subsidence took place in the porphyries at the east end, when the igneous action ceased,[*] and the heat abated; or the western end may have been subsequently raised; but no great difference of level between the two ends is required to explain the phenomena. The coal strata may have covered, and probably did cover, the porphyries, but it is not necessary to assume this. The strata on the opposite sides might be connected at one or both ends of the chain.

It is worthy of remark, that the two chains of porphyry, the Ochills and the Pentlands, run parallel to the great valley, bounded by the Grampians and the Southern Hills,[†] which constitutes the middle district of Scotland. If we suppose this valley to be partly the effect of denudation by an oceanic current from the south-west, these chains are precisely in the direction of the current, and may occupy what were originally minor cavities or troughs excavated by it, as our hypothesis assumes. If the valley is partly the effect of subsidence, these cavities may be minor local effects of the same cause, harmonizing with the greater in their position. The Garleton Hills are in the same line with the Pentlands.

The Calciferous Sandstones.—In the burn westward of Habbie's How the conglomerate passes into sandstone, the two rocks alternating at the junction. At Mickle Knock there is a bed of limestone near the junction, which may be considered as represented on the south side by numerous thin beds, and perhaps by the calcareous stratified claystones exposed in Lynedale ravine. Above these are the vast beds of sandstone of the Cairn Hills, on the north-west side of which, at Crosswood, carbonaceous impressions of plants appear, indicating the approach of the coal measures. Four-fifths of the substance of this sandstone consists of grains of quartz. Whence has it been derived? Very probably it is the *detritus* of the quartz rock, granite, gneiss, and mica slate, of the Argyleshire Grampians, and Islands; or the ruins of mineral masses which have disappeared, and of which the Long Island, Tirey, Coll, Islay, Jura, &c., are the remnants. With so many proofs of waste and destruction on the western mountains and islands of Scotland, there is no difficulty in accounting for the existence of a deposit of sand a hundred times larger than this; and in the currents of the ocean we have an agent adequate to its transportation. The Gulf stream, which has formed the banks of Newfoundland, has carried sand ten times farther. Why there is so much of the sandstone on the north side of the hills, and so little on the south; so much conglomerate on the south side, and so little on the north? are questions to which, perhaps, no better answer can be given, than that the form of the subjacent mass, and its position in respect to the current, might determine the transported matter towards one part in much greater proportion than towards another, and further, that the currents which laid down the detritus at one time, might, from changes in their force or direction, afterwards sweep part of them away.

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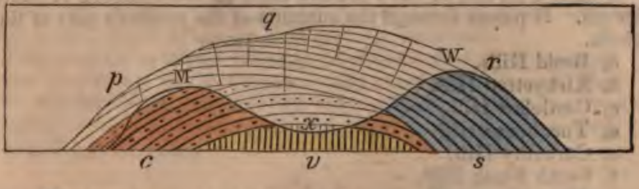
[*] On this principle, perhaps, we may explain the apparently anomalous fact, that the tilted sedimentary beds near the hills are often less inclined than those at a greater distance. When the porphyry was first pushed up hot, but in a solid state, the beds in contact with its sides would be most raised, and the others less and less as they receded from it. If the porphyry shrunk in cooling, and sank down, the upper sides of the beds leaning against it, being deprived of their support, would sink down with it, and assume a less inclined position; and this downward movement, like the upward one, would diminish in proportion to the distance of the beds from the porphyry. See, as an example, Mr Dunn's Section of the Gilmerton Coal-Field. Transactions of Natural History Society of Newcastle, Vol. I., Part II. See also the position of the beds at Carlops, p. 157. In the case of trap beds injected among sedimentary rocks in a state of fusion, the change of temperature would be greater, and the effect more marked. Examples are given at page 111 of this work.

[†] A general name is much wanted for this great range of mountains, extending from St Abb's Head to Portpatrick, a space of one hundred and thirty miles, and having a breadth of forty. The "Southern Scottish Alps" is quite inconvenient, even if it were not otherwise objectionable. Mr Murchison and Mr Sedgwick have borrowed the terms *Silurian* and *Cambrian* from ancient geogrphy, to discriminate geological objects. Might we not follow the example? A convenient term could easily be found. The Roman province of Valentia embraced the whole country between the Solway and the Firths of Forth and Clyde, of which these mountains occupy nearly two-thirds. Might they not be designated the *Valentian* mountains, and, when necessary, simply, the *Valentians*, as we say, the *Grampians*. The want of some such comprehensive term will be more and more felt in proportion as the geology of Scotland is more studied and discussed.

The sandstones of the north side of the hills seem to replace the conglomerates of the south, as shown in this diagram—which is a section N.W. and S.E. through Mount Maw and West Cairn Hill.

FIG. 77.



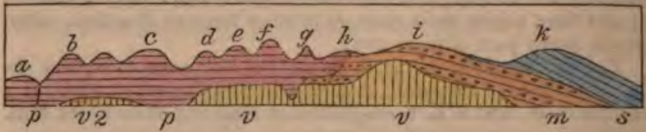
c, The conglomerate of Mount Maw.
v, The vertical slate.
s, The sandstone of Cairn Hill.

Originally, the conglomerate and the sandstone must have been in beds nearly horizontal. An upheaving movement, acting along an axis running N.E. and S.W., had raised the central part; the incumbent strata would then be bent into the arched form p, q, r;

and the upper parts being much fissured, would afterwards be broken up and carried off by currents. In Westwater, at the east end of Mendick Hill (1 in the map,) we have huge blocks of sandstone up to twenty tons, in vast numbers lying in the stream, which are, no doubt, the wrecks of the beds *p*, *q*, *r*. When the denudation was completed, and the hills raised above the ocean, the surface would have the outline *M*, *x*, *W*, which it now presents, bringing even the fundamental rock *v* into view at *x*. *M* is Mount Maw, and *W* West Cairn Hill. I found two or three beds of trap among the conglomerates in the basin of the Lyne, which may have aided in shattering the sedimentary rocks. There is a large bed of amygdaloidal porphyry near the head of Millstone Rig, one near its south end, and there are no doubt others which have escaped my notice.

Braid and Blackford Hills are evidently a continuation of the Pentlands. Though the country sinks, the rocks may be traced over all the intermediate space. They are of the same kinds, claystones, clinkstones, and porphyries; but the varieties are less numerous, and the bedded structure, if it exists, is much more obscure. I observed one greenstone vein. I cannot, however, give details, or speak with confidence of the structure of these hills, having merely walked over them two or three times.

FIG. 78.



This is a section of the Pentland Hills in the direction of their length. It passes through the summits of the southern part of the chain.

a, Braid Hills.
b, Kirkyetton Hill.
c, Castlelaw Hill.
d, Turnhouse Hill.
e, Carnethy Hill.
f, South Black Hill.
g, West Kipps Hill.
h, Broad Law, where the porphyries terminate; but they afterwards reappear on Mendick Hill.
i, Mount Maw and Millstone Rig.
k, The sandstone hills northward of Dunsyre.
p, Porphyry: *v*, vertical slate: *m*, conglomerate: *s*, sandstone: *v*2, is vertical slate supposed to exist, but not seen.

The porphyries of the Pentlands belong to an old formation, which is widely diffused. According to Brongniart, they are found as low as the mica slates, and as high as the lias. The rock known to be volcanic to which they have the greatest affinity is trachyte, and this, according to the same authority, is only found above the chalk.[*] Of the claystone porphyry (argilophyre) he says, that "it differs very little from trachyte: it has a base (pate) more rough, more dull, more varied in colour. It indicates rather a sedimentary than a crystalline origin."[†] Beudant thinks that a line can be drawn between the porphyries and the trachytes; but Boué contests this opinion, and is supported by Humboldt. He holds that the clinkstones have been ejected from craters in the manner of trachytes.[‡] In Mont Dore in Auvergne, "the trachytes pass by the most insensible shades into well characterised clinkstones."[§] Beudant's descriptions show that some of the Hungarian trachytes approximate closely to the felspars and clinkstones of the Pentlands. He distinguishes five varieties. The first and fifth consist chiefly of pumice, scorified substances, and mixed fragmentary conglomerates. The second, which he calls trachytic porphyry, is distinguished by the absence of scorified substances, *by its resemblance to the older porphyries, and by its containing quartz and calcedony.* The third, a species of pearl stone, contains *geodes of calcedony and opal.* The fourth puts on the character of a *hornstone or claystone porphyry,* having a *dull earthy paste, of a brick-red or greenish-yellow colour, containing crystals of quartz, of felspar, lamellar or glassy, and of black mica.* The descriptive terms marked by *italics,* comprehend most of the essential characters of the felspathic rocks of the Pentlands; and there is this additional trait of resemblance, that the Hungarian trachytes rest on transition rocks, and, in some cases, support the older secondary deposits. Dr Daubeny remarks, indeed, that the claystone of Arran presents numerous analogies with the trachytes of Hungary;[¶] and this claystone resembles some rocks of the same species in the Garleton Hills and the Pentlands.

There are rocks which can only be denominated "greenstones" in the Pentlands; but as they generally pass into clinkstone, their base consists most probably of that substance. Of the true dolerites or augitic traps, so far as I can judge, there are none among the porphyries.

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[*] Tableau des Terrains, p. 344—355.

[†] Classification des Roches, p. 113.

[‡] Geognostisches Gemalde Von Deutchland, 1829, p. 527, 528.

[§] Lecoq et Bouillet Vues et Coupés, p. 218.

[‖] Daubeny on Volcanoes, p. 7, 93—95.

[¶] Daubeny on Volcanoes, p. 105. Professor Jameson notices contemporaneous portions of quartz in the porphyries of the Pentlands, and crystals of quartz and glassy felspar in some of the other Scotch porphyries.—*Wernerian Memoirs,* Vol ii., p. 191-219.

I have not seen a single vein of greenstone in the porphyries of the Pentlands. There is one near Bevelaw, but it is in the vertical slate; and there is another westward of Torduff Hill, (*k*, Fig. 52, p. 135,) which is found piercing beds of sandstone. There are, besides, two or three beds of greenstone or amygdaloid in the basin of Lyne water, but they are among the conglomerates. There is a vein of heavy spar about a foot wide in Turnhouse Hill.

The general *strike* or direction of the beds of greywacké and clayslate in the Pentlands, is N.N.E. and S.S.W., or more correctly N. by E., and S. by W. The axis of the hills crosses the strata of the fundamental rock at an angle of about 30°.

Before leaving this subject, Boué's opinion as to some of the other igneous rocks of this country, may be quoted. Having examined both our traps and the volcanic products of Auvergne, he thus classifies the former.

Evidently Volcanic.—A black basalt near Mid-Calder, with grains of olivine and crystals of augite, and another like it somewhere near Edinburgh.

Probably Volcanic.—The basalt of Staffa—the traps of Arthur's Seat, the rocks of which are of the same species, and are similarly arranged with those of the volcanic districts of Auvergne and the Vivarais, (but the greenstone of Salisbury Crags is an exception)—the traps of Dalmahoy Hills—of Lamlash Island—of Dumbarton rock—and of Craglockhart Hill. The last, he says, (meaning, no doubt, the traptuff,) is very like a volcanic tuff.

Doubtful.—Salisbury Crag—the Castlehill—the Calton—Blackford Hill—North Berwick Law—Garleton Hills—and some traps at Linlithgow.*

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* Edinburgh Philosophical Journal, Vol. ii., p. 326.

GEOLOGICAL AGE OF PENTLAND HILLS.

THE geological age of the hills is by no means identical with that of the rocks composing them. It means the period, when either by an upheaving movement affecting the hills, or one of subsidence affecting the rocks on their flanks, they rose above the common level of the adjoining district. Thus the Pyrenees, though consisting of ancient rocks, had been elevated subsequently to the deposition of the chalk. Elie de Beaumont has generalized the facts which indicate the age of mountain chains with the happiest effect, and classed those of Europe into twelve systems, the most recent of which had undergone upheaving movements since the deposition of the older alluvium.[*] His leading principle may be explained in a few words. It is evident that sedimentary strata, sometimes less than an inch thick, composed of such materials as sand or clay, and found resting vertically on their edges, cannot be in their natural position, but must have been turned up since they were consolidated. The same remark applies to beds of conglomerate, consisting of finely rounded bowls six or eight inches in diameter, when found on edge as at Callendar, or on slopes as steep as the roof of a house, as in the Pentlands. If then, we find, on the flanks of a mountain, some sedimentary beds tilted on edge, which had of course been deposited on planes nearly horizontal, we conclude that the beds existed *before* the mountain was upraised, since we cannot otherwise account for their being forced out of their natural situation. Such beds are said to be *older* than the mountain ; that is, they are older than the date of its elevation. If, again, we find the tilted beds covered by other sedimentary beds which retain their natural horizontality, we conclude that the level beds had been deposited *after* the mountain was upraised, since they have not participated in the elevatory movement. Such beds are said to be *newer* than the mountain ; and the age of the mountain is defined by saying that it is *newer* than the one class of rocks, and *older* than the other.

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[*] Annales des Sciences Naturelles. Janv. et Fev., 1830. Boué had noted this fact as early as 1822.—Memoires Geologiques et Paleontologiques, Vol. i., p. 338.

FIG. 79.

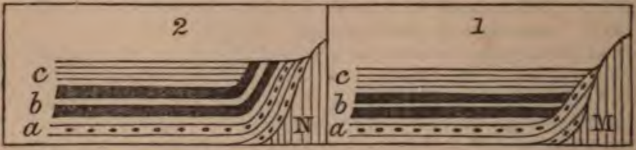

Fig. 1.—We find here that the mountain M has turned up the old red sandstone *a*, on its flanks, while the coal strata *b*, and new red sandstone *c*, retain their original level position. The two latter had, therefore, been deposited after the old red sandstone was contorted by the elevatory movement.

Fig. 2.—The mountain N here, has turned up both the old red sandstone *a* and the coal strata *b*; but the new red sandstone *c* retains its natural position, and was, therefore, deposited *after* the old red sandstone and coal were contorted by the upward movement.

The mountain M, in figure 1st, is said to be *older* than N, in figure 2d; and hence, by noting what beds are, and what are not, tilted or disturbed on the flanks of mountains, we can compare the *age* of one chain with that of another. There are many distinguishable groups of sedimentary rocks, and by taking these as terms of a scale, we can arrange the mountains into a chronological series. We cannot *integrate* the lowest of these terms in our measures of time, because we have no data to determine the number of *years* since the newest of the chains arose; but we can fix the precise order in which they arose, and tell which are newer and which are older than the others.

The mountain M, is said to be *newer* than the old red sandstone, but *older* than the coal measures.

The mountain N, is said to be *newer* than the coal measures, but *older* than the new red sandstone.

Let us apply this principle to the Pentland Hills; and as it is difficult to distinguish the effects of subsidence from those of elevation, let us assume, what is the more probable hypothesis, that the movement which raised them above the strata on their flanks, was one of elevation.

The conglomerate beds, consisting of smooth globes, which would not rest except on a surface almost perfectly horizontal, are found inclined at 30° or more. It is evident, therefore, that the hills have undergone *some* disturbing movement, since these beds are not in their original position.

Wherever the stratified rocks on the flanks of the hills are seen in juxtaposition with them, these rocks are disturbed. In Glencross Burn, (Section VI., *a*,) we have sedimentary beds ("*calciferous* sandstones") dipping away from the porphyries at 50°, where there is only a quarter of a mile of intervening space. In Bilston Burn we find the "coal measures" dipping S.E. at 30° or 40°. We can trace them from the Pennycuick road, to the junction of the burn with the Esk, over a space of a mile and a half, measured at right angles to their direction. Their true thickness, taking the mean dip to be 30°, should be nearly 4000 feet; but as Mr Bald's more accurate measurement gives a depth of only 2300 feet to the edge coal, it is probable that a fault exists, and some portions of the strata are twice presented. As we have the coral limestone near the upper observed limit,* we are sure that all these beds belong to the "coal measures," and the space covered with gravel, which separates the limestone from the porphyries, cannot be less than two-thirds of a mile. Thus we have the disturbing action of the hills, extending to a distance of more than two miles from their visible boundary, and tilting the strata through a depth of probably 4000 or 5000 feet. Farther east, at Straiton and Gilmerton, we find the strata in a highly inclined position; and the dip is always *away from the hills*, or away from their axis continued beyond their visible termination; in the latter case affording presumptive evidence either that the porphyries are prolonged under the surface, or that the upheaving movement which raised them, extended beyond them in a linear direction.

At Nine Mile Burn we find the strata of the coal measures and calciferous sandstones turned up, and placed completely on edge, for a space of probably 1500 or 2000 feet, (see Fig, 59, p. 153.) The space covered with alluvium, between the conglomerate of the hills and these vertical strata, does not exceed 150 or 200 yards.

At Carlops the calciferous sandstones, well exposed, are found dipping away from the hills at angles from 20° to 80°, (see Fig. 61, p. 157.) At Linton, the conglomerate passes into a claystone, and both dip away from the hills at angles from 20° to 40°, (see Fig. 69, p. 168.)

On the north side of the hills we find similar evidence of an upheaving movement, though in a less distinct form. In Braid's Burn we find strata of sandstone and shale dipping away from Braid Hills at 30° to 50°, (see page 98.) At Colinton, within less than a mile of the hills, the strata dip north-westward at 45° to 50°, (Section V.) Near Kenleith there is a small portion of the strata in a position denoting an upward lift, (Section VII., *k.*) At Cairn Hills we find vast beds of sandstone raised at one end, so as to dip N.W. at a considerable angle, that is, they dip away from the centre of the hills; and farther south we find large deposits of sandstone dipping W. and S.W.

If we suppose the movement of elevation to have taken place along an axis running through the hills N.E. and S.W., and terminating about Deerhope Rig, all the strata enumerated on both sides will be found to dip away from this axis, or from its western extremity, not indeed at equal angles, or with a rigid uniformity of direction, but with sufficient regularity to indicate an upward movement of the hills, as the one great cause of the disturbed position of the beds. The western dip of the sandstones from West Cairn Hill to Dunsyre, may be explained by supposing that the vertical lift diminished from Deerhope Rig westward to the point where it vanished, or that a transverse lift changed the dip.

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* There are two thick beds of limestone here, each containing shells, and about 400 feet distant from each other, measured at right angles to their planes. The lower, which contains encrinites, is sixty feet thick, but includes beds of shale. The upper also contains some shells. I did not ascertain its thickness.

The strata of West Cairn Hill extend over a horizontal space of a mile and a half, or eight thousand feet. If we assume that they were level when deposited, and have now a mean dip of 15°, their upper extremity (at *c*, Section XI.) must have been raised 2000 feet above its original position. At 12° of mean dip, the rise would be 1600 feet.

It has been found that sand thrown over a bank or ridge into still water, will form beds at a higher angle than 12° or 15°.* It is hence possible that the sandstone of Cairn Hills is in its original position ; but there are two facts adverse to this supposition. First, The sandstones which encircle the west end of the Pentlands, dip away in opposite directions from a common centre which is in the hills, where we would look for the seat of the upheaving movement. Second, *If sandstones had been deposited at a height of* 1800 *feet above the sea, they must have filled a multitude of the valleys in the Peeblesshire and Moorfoot Hills*, many of which must then have existed. Of the little valleys not a few are *culs-de-sac*, where any deposit would have found good protection, and it is quite impossible that every remnant of the sandstone should have disappeared from all these, if it had ever existed in them. Isolated patches of red sandstone are found along the course of the Nith, at Moffat, Applegarth, Kirkpatrick-juxta, Rae Know, and Annfield, and larger ones at Closeburn and Sanquhar. But none of these, I believe, ascend to a greater elevation than 600 or 700 feet, and all of them seem to be connected with the sea by defiles or valleys at a low level. I am inclined to think that no undisturbed sandstones are found in this district at a greater height than eight or nine hundred feet above the sea. The existence of this sedimentary rock, therefore, eighteen hundred feet above the sea in Cairn Hills, is another proof of an upheaving movement, independently of the inclined position of the beds.

Among the lowest rocks visible between Musselburgh and Bathgate, we find none resembling the crag of conglomerate at Turphin (*a*, Fig. 51, p. 132.) It may be considered as corresponding to the conglomerate *e*, Section X., which passes under the sandstone of West Cairn Hill. That sandstone thins off greatly to eastward; but, supposing that its depth has diminished to five hundred feet, and that the beds between it and those visible at *Woodhall*, (Section VI.,) are a thousand feet thick, it will follow that the detached mass of conglomerate *a*, has been brought up from a depth of nearly two thousand feet; in other words, that the part of the hills alluded to has been upheaved to that extent. This is merely a loose conjecture; but if characteristic fossils had been found in the deposit *e*, Section VI., or *g*, *h*, Section VII., which could be referred to a certain part of the series of strata, we would have been able to arrive at a more definite conclusion.

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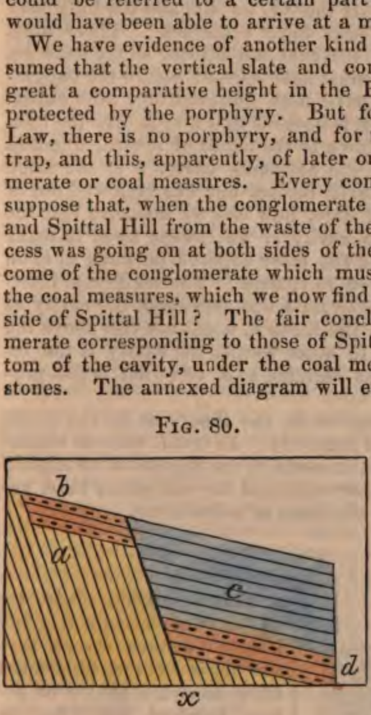
* Delabeche, Researches on Theoretical Geology, p. 50.

We have evidence of another kind to prove an upthrow. I assumed that the vertical slate and conglomerate were found at so great a comparative height in the Pentlands, because they were protected by the porphyry. But for two miles west of Broad Law, there is no porphyry, and for two miles more, only a little trap, and this, apparently, of later origin than either the conglomerate or coal measures. Every conceivable principle leads us to suppose that, when the conglomerate was forming at Mount Maw and Spittal Hill from the waste of the vertical slate, the same process was going on at both sides of these hills. What then has become of the conglomerate which must have occupied the place of the coal measures, which we now find in a deep cavity on the south side of Spittal Hill? The fair conclusion is, that beds of conglomerate corresponding to those of Spittal Hill are lying at the bottom of the cavity, under the coal measures and calciferous sandstones. The annexed diagram will explain this.

FIG. 80.



a, The vertical slate of Spittal Hill, about one thousand four hundred feet above the sea.

b, The conglomerate covering the same.

c, Part of the cavity in which the calciferous sandstones and coal measures lie, and as one or both thin off to westward, their entire depth here probably does not exceed one thousand feet.

d, The supposed prolongation of the conglomerate under the coal strata, at a depth, according to this hypothesis, of one thousand two hundred, or one thousand five hundred feet below *b*.*

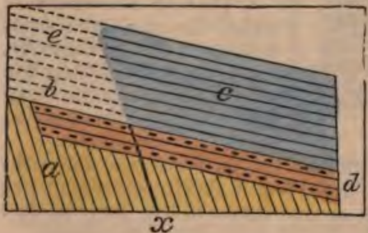
* For the sake of simplicity, I have supposed the dislocation simply to change the level of the strata, without tilting them on edge, as we find them at Nine Mile Burn. In dislocations there are two effects to be distinguished—the change of level, which may take place without a change of dip—and the tilting, or angular movement of the shifted beds, which produces a change of dip, and probably depends on lateral compression. A mountain mass shaped like a parallelogram, if pushed upwards, would perhaps merely change the level of the fractured beds. One, with wedge-shaped sides would both change the level, and tilt the lower portion of the fractured beds.

x, A supposed slip or dislocation.

The conglomerate is an older rock than the strata mentioned, and, if it exists at all, must underlie them. Supposing a slip or fault to exist at *x*, it follows that the hills have been raised, and the non-appearance of the conglomerate behind Nine Mile Burn (Fig. 59, page 154,) is accounted for. If there is no slip, and the hills have not been raised, how are the facts to be explained? There must have been a cavity here when the coal and inferior strata were deposited in it, and that cavity must have existed before the conglomerate was formed, or must have been hollowed out afterwards. If the cavity existed before, it is obvious that a rock like the conglomerate could not be laid down to the depth of several hundred feet at *b*, without filling up the adjoining cavity *c* to the same level. If the cavity did not exist before, but was hollowed out of the conglomerate and vertical slate, how can we conceive that the portion lying in the sheltered cavity *c*, was swept away to make room for the coal strata, while the more exposed portions *a*, *b*, on the mountain top, were suffered to remain? The legitimate inference is, that when the conglomerate *b* was deposited, the cavity as we now find it did not exist; the rocks *a*, *b*, did not rise above the rocks *c*, *d*, as they now do; in other words, the cavity is the result of a dislocation which has elevated *a*, *b*, or (what is less probable) depressed *c*, *d*.

This argument is not dependent on the theory as to the origin of the porphyries, proposed at page 181. In truth, without violent and unwarranted assumptions, it seems to me impossible to explain the relative position of the older rocks and the coal strata here, unless we admit a movement of elevation or subsidence.

FIG. 81.



This admission made, let us see what consequences follow. We have shown that the mass of the hills must have ascended twelve or fifteen hundred feet. Let us suppose them replaced in their original position, as in the annexed figure. The portion of the conglomerate *d*, will then be in a line with *b*; but it is evident that the calciferous and coal strata *c*, must then have stood more than a thousand feet above the present summit of Spittal Hill; and since strata, consisting originally of loose sand and mud, could not have been formed with their edges truncated as in the figure, the necessary inference is, that they extended northward over the hills, as shown by the dotted lines *e*. We thus arrive at the conclusion, that the coal measures may have originally extended across the hills at this part of the chain; but as the undisturbed sandstones are not found at a greater height than nine hundred feet above the sea, the Pentlands must then have been lower by one thousand feet, or more, than we now find them.

One mile west of the locality just described, at the east side of the village of Carlops, we have the dislocation distinctly shown. The conglomerate is exposed to a great depth on the new road, and, from an examination of the upper part of the river, we know that it is in beds dipping S.E., and whose direction is S.W. and N.E. The strata of sandstone, shale, and limestone in the water course below the village, (see Fig. 61, p. 157,) have very nearly the same direction with a rather higher inclination, and, if no disruption had taken place, the one series should have been the continuation of the other. They are, however, perfectly distinct and dissimilar, though the truncated ends of the two series are apparently only divided by the burn, which has worn out a passage in the fissure produced by the dislocation. It is evident, too, from the great depth of conglomerate displayed here, that it originally extended farther southward, and that its prolonged portion must exist below the sandstone and shale exposed in the water course.

A little westward we have the dislocation continued in the trough-shaped valley described page 162, which valley is very nearly in the same line with the fissure just mentioned, forming the water-course at the east end of Carlops. The bed of trap which had once filled the long valley, terminates at the village. It was perhaps 300 feet thick or more, and was in all probability the agent by which the rocks here were ruptured. About half a mile west from the village, the strata of sandstone and shale, which rise in this direction, become large-grained and pebbly, and pass into the conglomerate of the hills, which is here found on the south side of the valley, (about *i* in Fig. 64, page 162.) The inference I draw from this is, that the dislocation here has shifted the rocks through a more limited space, and that it increases in depth as we go eastward. At Nine Mile Burn, for instance, the shift may have been 1200 feet; and at the point two miles westward, in the long valley, only 100 or 200.*

Nearly on a line with this, and two miles further west, we have the beds at Lyndale, (see Fig. 69, page 168,) not ruptured, but bent very curiously from the horizontal position into one inclined at 25° or 30°. It may be fairly inferred that this took place at the same time with the dislocation at Carlops, and was the work of the same agent.

* The reason why the shift is less here may be, that the adjoining strata of sandstone partook of *some* of the upheaving movements which changed the level of the conglomerate on the hill. See this point illustrated at page 138. Where a great change of level has taken place, analogy is certainly in favour of Mr Lyell's principle, that it was effected by a *succession* of movements.

Did the coal measures at one time cover the porphyries of the Pentlands?—Evidence has been already adduced to show that these rocks once covered the western part of the Pentlands, where the hills consist of conglomerate and clayslate. But the coal strata are thin there, and the difference of level between the lower beds and the adjacent hills is comparatively small. Farther east, towards Loanhead and Dalkeith, these strata swell out to an immense thickness; and, as their surface is nearly of the same elevation, it follows that the cavity in which they are lodged must descend to a very great depth. The question, therefore, rests on materially different grounds at this locality. We have here to consider what the amount of displacement caused by the upheaving of the hills is, and what would be the relative position of the porphyry and sedimentary beds before it took place. The best means we can find of estimating the displacement, would perhaps be this: We may conceive the lowest sedimentary bed to have its side firmly inserted into some accidental hollow in the porphyry; so that, when the latter ascended, it would carry up with it the nearest portion of the sedimentary bed, bending it and all the superimposed beds into a curved form. If we now suppose the outcrop edge of the visible bed nearest the hill not to have been truncated by denuding agents, but to be in the position to which it was lifted—the undisturbed portions of the upper beds, at a distance from the hills also, to be in their original position—and the two to be nearly on a level, which is not far from the truth—then the thickness of the whole series, which we can measure across the outcrop, gives us the *minimum* of upward lift. The tilted beds of the coal measures, according to Mr Bald, are 2300 feet thick. If we add, by a very moderate estimate, 1200 feet for the calciferous sandstones, we have a thickness of 3500 feet; and, according to our hypothesis, the eastern part of the Pentland hills must have been lifted up through this space at least. The *lift* might be greater; because the lowest tilted beds may have been truncated to the extent of some hundred feet; or the porphyry, after forcing a passage through the sedimentary rocks, might ascend, while they slipped downwards on its flanks, instead of ascending with it.* Let us now suppose the porphyry replaced in its original position, 3500 feet below where we find it, and the sedimentary strata to stretch out horizontally, with their upper surface at the level of Pennycuick, about

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* Along what is called the "Penine Fault," extending from Newcastle to the sources of the river Aire, over a zigzag line of 110 miles, the *lift* amounts in some parts to 4000 feet. Professor Phillips remarks, that the absence of igneous rocks, at all parts of this *fault* south of Cross Fell, is an important fact in reference to the causes of such dislocations, (Geology of Yorkshire, Part ii. p. 253.) The application of the principle assumed in the text, to the tilted beds at Callendar, would lead us to suppose a *lift* of 10,000 feet there, or nearly two miles. This result is startling; and it is possible that the argument may involve some fallacy which has escaped my observation.

600 feet above the *existing* sea. The present summit of the highest porphyry hill, which is 1300 feet above Pennycuick, must then have been 2200 feet below it. *It follows that the upper part of the coal strata might not only extend across the hills, but might cover them to the depth of* 2200 *feet.* The hypothesis upon which this calculation proceeds, involves so many arbitrary elements, that the conclusion deduced from it is not entitled to be considered as any thing better than a loose conjecture. I felt the insecurity of the ground, but did not wish to pass over the subject entirely.

In the movement which raised the western part of the hills, the coal measures and inferior strata near Linton and Carlops, had participated, though to a smaller extent. It may be added, that fragments of sandstone are strewed over the highest parts of the Pentlands. They are abundant on North Black Hill, at an elevation of nearly 1700 feet above the sea.

Though the upward movement of the hills has tilted the lowest beds of the coal measures and inferior strata, it has not affected the whole. It was shown at page 153, that beds of sandstone, very nearly horizontal, are found almost in contact with the tilted strata at Nine Mile Burn, and bearing the same relation to the latter which the formation *c*, in Fig. 79, bears to the formations *a* and *b*. The inference is, that the horizontal beds were deposited after the upward movement took place. Mr Bald notices a "flat coal" in the eastern part of the Mid-Lothian field, which he thinks had been deposited after the edge coal was tilted. Mr Murchison, I believe, also adopts this opinion, and has bestowed the name of "Roslyn sandstone" upon the deposit. Lord Greenock, however, whose judgment is entitled to much weight, considers the flat coal as merely the upper part of the other. I have noted what I saw, and mentioned the deductions to which it led, but do not wish to be held as speaking with confidence on the subject. If this upper formation is posterior to the last elevation of the Pentlands, we may suppose that the Roslyn sandstone was chiefly formed out of the wrecks of the coal measures, when they were shattered by the last upheaving movement.

Professor Sedgwick is of opinion that the new red sandstone of the north of England had its origin in this way. "It consists," he says, "of sand, small pebbles, and other incoherent materials, drifted to the lower and outer edges of coal fields: even at this day it is at many places but imperfectly cemented, and it contains, though rarely, a few drifted coal plants. In some districts it is perfectly conformable to the upper coal strata on which it immediately rests, and seems to form a regular link between them and the overlying formations; but, considered on the whole, its position, so far as regards the inferior strata, is discordant." He thinks also that the elevation of the carboniferous chain was probably the mechanical cause of this deposit.* Mr Delabeche adopts the same view. He considers the new red sandstone as composed of the debris and detritus of the older rocks, produced by their disruption and dispersion.[*]

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* Geological Transactions, 2d Series, Vol. iv. p. 58.

The last upward movement of the Pentlands seems therefore to have taken place between the deposition of the coal measures and that of the Roslyn sandstone. Professor Sedgwick is of opinion,[†] that the Lammermuir range was raised previous to, or during the formation of the old red sandstone. Of course, it should not have disturbed the coal measures; and this is consistent with my observations at the few localities I have visited.

According to the hypothesis formerly proposed, (page 179,) the order of formation among the rocks of the Pentlands would be this:—1. The greywacké and clayslate, the origin of which it was not thought necessary to discuss. 2. The conglomerate, formed from the detritus and debris of the preceding. 3. The porphyry, produced by successive eruptions from a submarine crater, and deposited upon the conglomerate. 4. The calciferous sandstones, formed from the detritus and debris of all the preceding rocks—namely, the vertical slate, the conglomerate, and the porphyries, along with siliceous sand transported from a distance. 5. The coal strata formed from the waste of the sandstones—from that of such parts of the porphyry and conglomerate as might remain uncovered—from decomposed vegetable matter—and from transported siliceous sand. 6. The Roslyn sandstone, formed partly of the wrecks of the coal strata, shattered by upheavals of the Pentlands; partly of the waste of the porphyries and conglomerates, which were probably now again largely uncovered. If the theory as to the origin of coal, given at page 114, be correct, the beds of the coal measures must have been sometimes under, and sometimes above water.

Relative Age of the Igneous Rocks.—As the amygdaloids and the sedimentary deposits, mixed with the porphyries, seem to prove successive superposition, it follows that the lowest beds are the oldest; and the newest will be the red or brown clinkstones and claystones, which extend along the south side of the hills from Hillend to Mendick. The traps are newer than the porphyries, as they disturb rocks formed after them. The oldest of the traps is probably that of Carlops, which, along with distinct grains of augite, contains quartz, calcedony, and amethyst in veins, and has in some parts the aspect of a clinkstone. It approaches, if it does not belong to, the porphyry series. The bed of trap southward at Whitefield, and the other at Dunsyre, are in the calciferous sandstones. The vein near Torduff Hill disturbs beds of sandstone, which are perhaps nearly as recent as the coal strata. The vein at Bevelaw being accompanied only by the clayslate, through which all the veins must have passed, we have no certain clue to its age; but its character assimilates it to that last mentioned. The traps of Achinoon Hill, Corston Hill, and Dalmahoy Crags, probably belong to the same epoch. We can only say, that they have disturbed rocks nearly coeval with the coal. All these traps seem to be dolerites.

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[*] Manual, p. 362, 3d Edition.

[†] Geological Transactions, Vol. iv. New Series, p. 56.

It has been already remarked, that the trap rocks which present themselves at the surface, are rather the outward sign, than the actual cause, of upheaving movements. *The trap veins and beds, therefore, in the Pentlands, or on their flanks, were probably thrown out about the period when the great movement took place, by which the mass of the hills pierced the coal strata, and rose above them.* This was evidently prior to another great movement, which lifted the hills and the sedimentary rocks on both sides of them above the sea; for the traps themselves bear marks of the action of water.

Since the remarks on the influence of the traps (page 101) were printed, new light has been thrown on this subject by the researches of Messrs De Beaumont and Dufrenoy on Etna and Vesuvius. The former has shown, by a masterly chain of reasoning, founded on observations carefully made, that Etna owes its conical form and vast height of 10,000 feet, not simply to the superposition of lava and fragmentary matter, stratum above stratum, but chiefly to a movement of elevation from below. The mountain consists of an *outer* cone of modern ejections, inclined at very low angles, seldom exceeding 7° or 8°, and an *inner* cone or nucleus, formed of older ejections, which had been laid down originally on planes almost level, but have since been raised into positions inclined at 25° or 30° to the horizon. In this upraising, the rocks were fissured, the principal fissures being *stellaform*, or disposed like radii round a centre; and through these fissures new eruptions took place. The interesting fact which bears on the theory of the trap rocks is this—that an upheaving movement, which generally fissures the mountain, takes place independently of any emission of lava or tuff; that the quantity of these thrown out may bear an insignificant proportion to the movement which they accompany; and that, in fact, they are but incidental jets, or extravasated portions of the tumified mass below—signs, in short, of the activity of the upheaving power, but not affording a measure of its force or effects.* The case of the trap rocks seems precisely analogous. Their presence indicates that the upheaving agent has been at work; but the quantity visible may be trifling, while the elevatory movement has been great. In another respect, the eruptions of Etna elucidate phenomena connected with the traps. Lava often fills the bottom of a fissure many miles in length, and penetrates to the surface at two, three, or half-a-dozen of points along that fissure, spreading around each in a small bed or beds. In like manner, we find a series of narrow beds of trap, ranged along a line, as if connected with some trough or fissure filled with the same matter, deep under the surface, (see page 96.)*

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* Memoires pour Servir à une Description Geologique de la France, Tom. IV. p. 118.

Two deep defiles extend across the northern part of the Pentlands into Logan House valley, and by it and Glencross form a communication with the basin of the Esk. They are at the east and west ends of North Black Hill; and it deserves attention that they occur at the junction of the conglomerate with the felspar. The one is the ravine *x r*, Fig. 54, and *x*, Fig. 55, (pages 146, 147.) The other is of the same form, and rather deeper. The latter probably descends 800 feet below the summit of the Black Hill. In Logan House valley, though the unequal extension of the beds laterally had formed an original cavity, there is no doubt that it has been subsequently enlarged. The burn flows in a trough-shaped hollow, on both sides of which the beds are visibly truncated. This hollow, which is about 150 feet wide, and probably 50 or 100 deep, is filled with gravel, on the top of which the stream has formed its bed; but the hollow must have been cut out by a more powerful agent, namely, by tides or currents. Deep seas are supposed not to excavate valleys, and it is probable that these defiles were cut out when the water stood only a little above the level of the hills, by tides and currents operating along lines of fracture produced by upheaving movements.

If the excavation of the two transverse valleys is due to the causes supposed, the ancient ocean must have remained a long while at or near the level of these valleys, and traces of its action should be discovered on other parts at the same elevation. Not having attended to this point during my survey of the hills, I can say nothing positive upon it. I content myself with suggesting it as a fit subject for enquiry, whether a certain correspondence of level may not exist in those bare escarpments and abrupt declivities which every one must have observed on the north side of the hills; in other words, whether something like lines of aqueous erosion, in successive stages below one another, may not be traced, marking the longer sojourn of the ocean at certain elevations. We canno , however, expect to find those traces very distinct. They must have been partially obliterated by the violent irruption of the waters which deposited the diluvium, and which necessarily left other marks on the surface not now to be easily distinguished from the first.

When the sea retired and left the hills dry, the burn would begin its excavation. It has cut a fissure about eighty feet deep and two or three yards wide, in the upper strata of the conglomerate. From the bottom of this the water pitches down almost perpendicularly, forming a pretty cataract which undermines the rock, and as usual eats its way slowly backward. From the outer margin of the rock, facing the east, it has receded about fifty yards, having hollowed out a cove of this length, about thirty-five yards in depth, thirty in width at top, and seven at bottom. This is entirely the work of the burn and the atmosphere; and if we knew how much the waterfall receded in a century, we would have a scale by which we could estimate the length of the period since the hills were laid dry, and the stream began to flow.

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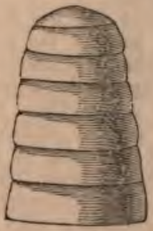
* Twelve different orifices, vomiting lava, have been observed on one line of fissure. —(Scrope on Volcanoes, p. 152.)

Fossils.—I found two fossils in the greywacké slate near Deerhopefoot, in the small burn marked *g* in the map of the hills. They are not now in my possession, having been sent for inspection to a friend who did not return them. The figure on the margin represents one of them. The shape is that of a truncated cone, and the specimen was about an inch in length, and rather more than half an inch in diameter. It was considered an orthoceratite by Dr Hibbert, and has distinctly the character of that class of shells. The other, which was thin and about an inch and a half broad, seemed to consist of several cohering fragments, which had some resemblance to parts of small trilobites. The orthoceratite is a marine *multilocular* or many-chambered shell. The animal lodged in a cavity at the broad end. The chambers are simply air-vessels, and the shell is thin, its use being merely to float its inhabitant. A siphuncle or small pipe passes through the centre; by filling this with fluid, the animal, with its shell, becomes heavier than water, and sinks; by emptying the siphuncle, the animal becomes specifically lighter than water, rises upward, and floats. The orthoceratite is one of the most ancient fossils. It is found among the schists which contain the first vestiges of organized beings; it abounds in the transition rocks, and is not found at a latter epoch than that of the coal measures.*

FIG. 82.



The General Sections I. and II. connect the Lammermuir Hills with the Ochils; but for those who are not possessed of other geological works, it may be convenient to have a general view of the structure of the great central valley of Scotland, and its relations with the hilly regions that bound it. This is exhibited in the annexed diagram, which is founded partly on my own observations, partly on information derived from other sources.

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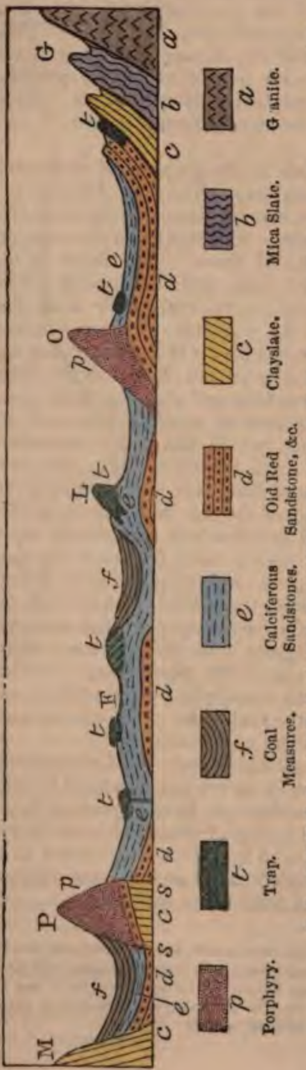
* See Dr Buckland's Bridgewater Treatise, p. 363; and in particular the preceding section, p. 310, where the structure and functions of the cognate species of Nautilus are described with admirable beauty and felicity. The specimen from the Pentlands seems to belong to the *Orthoceras simplex* of Deshayes.—Description des Coquilles Characteristiques des Terrains. Paris, 1831. p. 217.

FIG. 83.

IDEAL SECTION FROM MOORFOOT HILLS TO THE GRAMPIANS.

The Vertical Scale is to the Horizontal in the proportion of 15 to 1.



M, Moorfoot Hills, a part of the Lammermuir range.

P, Pentland Hills.

F, Firth of Forth, with the trap (*t*,) of Corstorphine Hill on the one side, and Dunearn Hills on the other.

The first *t* northward of the Pentlands, represents the trap hills at Ratho.

L, Lomond Hills.

O, Ochil Hills.

G, Grampians at the Highland border.

No precise line has been followed, because the purpose was simply to assemble in one diagram the objects necessary to elucidate the relations of the different rocks, and the order of superpostion. It may however be considered as corresponding generally with an irregular line, passing from Howgate across the Pentlands to Ratho, thence running northward to West Lomond Hill, and then northwest to Glen-Almond beyond Crieff. To avoid complexity, a multitude of minor details have been omitted. The northern part from O to G, is borrowed, though not literally, from Mr Lyell's instructive Section of Forfarshire, in the Geological Transactions, Second Series, vol. ii.

s, *s*, Are faults at the two sides of the Pentlands, marking the supposed fissures produced by their upheaval. There are probably similar faults on the flanks of the Ochils, but not having ascertained their position, I have not inserted them.

Professor Sedgwick observes, that the mountain limestone thins off and subdivides as we proceed from the central parts of England towards the Scottish border. The districts on this side of the Tweed, exhibit a similar progressive change. In the Lothians and Peebles-shire the limestone beds are thin, and bear an extremely small proportion to the masses of sandstone and shale which are associated with them. The aggregate thickness of all the beds is probably from sixty to eighty feet. In Cumberland the scar limestone alone is 600 feet thick, and the associated beds are 200 more, making a total depth of 800, or ten times the depth of ours.* In Fife, Mr Landale estimates the aggregate thickness of the limestone beds under the coal, at from twenty to forty feet. Northward of the Ochils, the upper beds of the calciferous sandstones are wanting, and very little limestone is seen in the lower part. Dr Macculloch's map exhibits it only at one locality near Muthil, and there it is probably insignificant in quantity; for most of the lime used in Perthshire is carted from Loch Earn, or imported by sea.

Dr Macculloch may be said to have expunged the Mountain or Carboniferous limestone from the list of Scottish formations; for in his map it is marked merely by narrow interrupted lines, never by spaces of any breadth. The coal measures and his old red sandstone generally appear in contact; and he says, expressly, in his Memoir (page 85,) that the mountain limestone is often wanting between these two formations.

The group *d* is, perhaps, nearly one thousand feet deep in some parts of the Pentlands. Its existence between P and O is purely conjectural. In the neighbourhood of Comrie I estimated the depth, from its junction with the schist to the flat sandstone near Drummond Castle, at seven thousand feet. The prevailing rock is chiefly conglomerate. At Callendar the formation attains a depth of nearly ten thousand feet; but the conglomerate beds are mixed with others of homogeneous sandstone, which constitute probably more than a half of the deposit. The outer parts of the schist at Loch Katrine and Comrie dip N.W., or away from the conglomerate, which seems to rest on their ends; but this is no doubt an anomaly. The common dip, according to Dr Macculloch, is S.E., and it is so represented in the diagram.†

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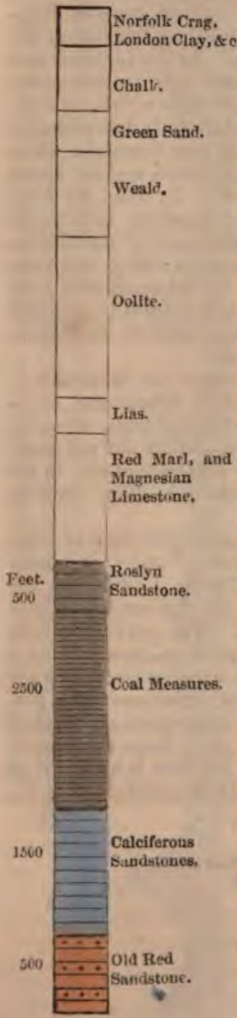
* Geological Transactions, vol. iv. New Series.

† Memoirs accompanying Map, p. 76.

FIG. 84.



Depth of the formations in this district compared with those of England.—The groups above the Roslyn sandstone, which form about three-fifths of the whole sedimentary rocks in England, are entirely wanting in this district, and indeed exist nowhere in Scotland, with the exception of some small patches in Morven and two or three of the Western Isles, and at Brora in Sutherland. Whether they never existed elsewhere, or after being formed were swept away, is a question which geologists have not ventured to decide.

The section on the margin exhibits the whole series found in Scotland and England, in their order, and with their proportional depths. The shaded spaces represent those which are found in both countries, and the white spaces those which are wanting here, but exist in England. The depths in figures on the margin are those of the Scotch rocks. Their aggregate amount is 5000 feet. The depth of the corresponding groups in England, substituting the lower part of the new red sandstone for the Roslyn sandstone, is 4500 feet. It is the *average*, not the extreme depth that is here represented, and in this average the Fife rocks are meant to be included with those of the Lothians.

I have taken the thickness of the English groups from the second edition of Delabeche's "Tabular and Proportional View."

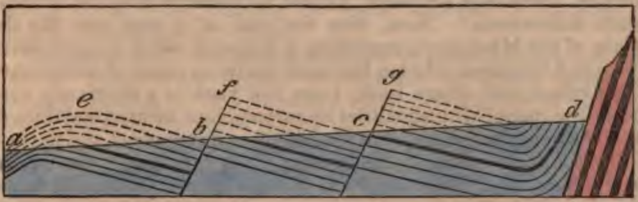
The thickness of the sedimentary rocks here varies so widely, as to render any thing like a correct average impracticable. But the preceding pages have put the reader in possession of the details; and it would require more time to explain the grounds on which the depth in feet assigned to each group in this diagram was adopted, than the object would justify. The trap beds, as adventitious deposits, are excluded.

ALLUVIAL PHENOMENA IN PENTLAND HILLS AND MID-LOTHIAN GENERALLY.

The alluvial phenomena are of four descriptions:—1. The waste and removal of portions of rock by water, and marks of abrasion on the surface. 2. Deposits of clay, gravel, and sand. 3. Erratic blocks. 4. River channels cut by the streams. These deserve a much more careful study than I have been able to give them.*

The *faults* of the coal strata supply us with striking evidence of the denuding operations of water on a grand scale. We may take as an example Mr Bald's section of the Alloa coal-field.†

Fig. 85.



- *a, b, c, d,* The present line of the surface, *a* being the shore at Alloa, and *d* the Ochil Hills. The length of the line *a, d,* rather exceeds six miles.
- *b,* The position of the great south slip, or fault, which has raised the strata no less than 1230 feet.
- *c,* The position of the great north slip, which has raised the strata 700 feet.

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* Two able geologists are at present engaged in examining the superficial deposits of the central district of Scotland—Mr David Milne and Mr Smith of Jordanhill. The latter has published the first fruits of his researches, in a valuable article in the Edinburgh Philosophical Journal for October 1838. The former read an elaborate and instructive Memoir on the subject, in the Royal Society last spring.

† Memoirs of Wernerian Society, Vol. iii. p. 123.

When the upward lifts which produced these rents took place, it is evident that the surface must have presented a broken outline, of which the salient points were *e, f, g*. There must have been an eminence at *g*, presenting a profile like Salisbury Crag, having a sharp crest, and a steep precipice facing the south, of five, six, or seven hundred feet in height, measured across the plane of the beds; that is, an elevation equal to that of Arthur's Seat above the King's Park. A similar ridge must have existed at *f*, having nine or ten hundred feet of vertical elevation; and there must have been a third rounded swell of uncertain height at *e*. Now, the whole of these vast masses of rock, extending over a base of six miles, from the Ochils to the Forth, have been swept away; and, instead of the serrated outline *e, b, f, c, g, d*, we have the slightly undulating line *a, b, c, d*, which, with its covering of clay and gravel, completely conceals from us the marks of those mighty convulsions that disturbed the rocks below, and are brought within our knowladge only by the labours of the miner. The matter removed in this single locality, must be nearly equal to the part of Pentland Hills east of Bonalley Ponds. Had a few thick beds of trap been intermingled with the fragile coal strata, a much larger portion of the latter would have resisted the denuding action of the tides or currents which removed them, and the surface would have been more uneven. So numerous are the *faults* which have raised one part of the crust of the earth and depressed another, that a square league, it has been supposed, cannot be found in England without such dislocations.* Now, take the case of a vast area like the plain of the Mississippi, stretching a thousand miles in each direction, and fractured into ten thousand portions, some of which have been raised, and others sunk, from one yard to a thousand: conceive the incredible inequalities its surface, thus fissured and shifted, must have presented, and that all these have disappeared, and in their room we have a remarkably uniform plain. A little reflection on these facts, will convey an idea of the gigantic process of waste and denudation by which so many asperities have been obliterated, and the surface worked into the slightly undulating form it presents. That water was the agent which effected the change, is proved by the enormous deposits of clay, sand, and gravel, scattered over the surface, or filling up the yet remaining hollows of the rocks, and by the thousands of water-worn boulders found in these deposits, fifty or a hundred miles from their original localities. It is scarcely necessary to remark, that though the dislocations took place at very different epochs, this does not affect the argument.

It has already been shown, that strata belonging to the conglomerate, calciferous sandstones, and coal measures, have been swept away to the depth of 1000 or 2000 feet from the summit and sides of Pentland Hills, and from the low country between Musselburgh and Linlithgow. These have disappeared; and the fact that the stratified rocks rise to a considerable height here only when they are protected by masses of trap, indicates with sufficient clearness that the existing inequalities are due to the violent removal of vast quantities of matter. This is strikingly shown in the section previously given at page 96, to which the reader is referred. The denuding agent has acted most energetically in the channel of the Firth, where the naked projecting traps of Inch-Garvey, Inch-Colm, Cramond Island, and Inch-Keith, with Fidra, Craigleith, and the Bass, divested of the sedimentary envelope which once covered and environed them, stand forth as monuments of its power. When we find that this channel has been hollowed out to double its usual depth (thirty-seven fathoms) at Queensferry, where the free passage is contracted by trap hills and an islet to three quarters of a mile in breadth, we see the reason why valleys should be deep in proportion as they are narrow, and why the flanks of hills standing near one another are often so sharply cut down.[*] We perceive, also, that as tides can effect such changes, we should not unnecessarily call in the action of *debacles* or oceanic currents. We have here, too, a key perhaps to some singular facts presented by certain lakes and estuaries; that Loch Ness, for instance, is absolutely deeper than the German Ocean; and that some parts of the bottom of the river Amazon, are lower than that of the sea into which it discharges its waters.

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* Delabeche's Researches in Theoretical Geology, p. 45. The term he uses is, "eight or ten square miles."

The summits of the Pentland Hills are in general swept bare and clean. There is no coating of clay, and the stones visible are usually portions of the subjacent rock, loosened by weathering, while the heavy travelled masses are found on their declivities, or in the valleys. The chief exceptions, so far as I remember, are the following:—Carnethy has on its summit a great pile of stones, collected, it is said, for the Beltane fires in ancient times, and evidently torn up from the rock below. North Black Hill has a covering of clay mixed with gravel, of which ninety parts in the hundred belong to the subjacent felspar. Along with these are seen, on the east end of the hill, blocks and small pieces of sandstone, fragments of conglomerate, and a few travelled boulders. Above the gravel is a covering of three or four feet of peat, which is wanting at the east end. West Kipps Hill, which has been cut into the form of a sharp cone, is itself an admirable specimen of diluvial action, (see Fig. 57.) In the west branch of Chapel Burn, in North Black Hill, (at 14 in the map,) there are fragments of sandstone up to ten tons in weight, and a bed of soil fifty or sixty feet thick. This is simply because it forms a deep and sheltered cavity. The soil and gravel on the summit of North Black Hill, seem to be derived chiefly from the decomposition and disintegration of the felspar rock, the debris of which are found at the north foot to the depth of fifty feet or more. The few fragments of sandstone mixed with the debris, may be remnants of the beds which we have reason to believe once covered it, or may have come from Hare Hill or East Cairn after the original covering was removed. The small patches of conglomerate on the west end of this hill, are unquestionably remnants of a bed which once extended over a great part, if not the whole. The conglomerate seen at the north end of Belld Hill is probably a portion of the same bed. In Loganhouse valley, at many points deep deposits of soil and gravel are seen. At the Compensation Damhead, the true bottom or water-worn cavity in the rock, was found to be about fifty feet below the surface of the alluvial gravel which previously occupied the water-course. On Allermuir Burn, the deposit of soil is probably 100 feet thick. This fact is instructive. It is a wide open valley, descending from the N.E. and opening to the S.W. If we suppose a current flowing from the W. or S.W., it would find no outlet on the east here, till it rose 300 feet above Loganhouse valley, and, being checked in its course by the eastern barrier, the clay and gravel it bore along would be deposited in this cavity, which is merely the eastern portion of the valley just mentioned. No valley in the hills opening to the E. or N.E. is filled with soil in this way.

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[*] The depth of the Firth is generally in the inverse ratio of its breadth. Betwixt Dirleton Common and Elie, breadth nine miles, extreme depth thirty-two fathoms. Betwixt Aberlady and Wemyss, breadth twelve miles, depth twenty-two fathoms. Inch-Keith and Kinghorn, depth twenty-six fathoms; Burntisland and Wardie, sixteen fathoms; Cramond Island and Inch-Colm, nineteen fathoms; at the Ferry, thirty-seven fathoms; opposite Hopetoun, ten fathoms; from Blackness upwards, eight fathoms. These are the depths at low water, to which three fathoms must be added for the rise at spring tides.—(See Thomas' Survey of the Forth.)

In the low ground about a mile from Linton, Westwater has cut a channel 500 feet wide and 100 feet deep, through a bed of gravel, of which perhaps less than one-half of the thickness is displayed. This gravel has some sand mixed with it, but almost no loam or clay, and consists chiefly of transported stones, of which the greater proportion are sandstone. There are but few of the rolled masses of conglomerate. It forms a large alluvial plain, covering all the rocks in the bottom of the valley. We see here the debris of many large beds originally existing to the westward and northward.

Tails of Alluvium on East Sides of Hills.—The deposits of gravel, or gravel, clay, and sand, are numerous and deep in the basin of the Forth. In general, they occupy natural cavities in the strata, or they are found on the east side of projecting masses of rock, forming tails to them, or long round ridges. The large bed of clay and sand extending from Edinburgh to Granton and Newhaven, which has been pierced, it is said, to the depth of one hundred feet in the Botanic Garden, I consider as the *tail* of Corstorphine Hill. It is furrowed with three small valleys, nearly straight, which are delineated in Knox's map of Mid-Lothian;

and there are three indentations in the line of the ridge, through which we may suppose the currents to have passed which scooped out these valleys. Their direction is precisely parallel to the ridge of the High Street, and the corresponding valleys of the Cowgate and North Loch. The trap hills at Ratho (eight miles west from Edinburgh) have a similar tail of clay on the east side, which is also cut into subordinate ridges, corresponding to breaks in the line of the hills. The clay in these deposits is full of large boulders, up to ten or fifteen tons in weight, and generally rounded. Among them are seen a few of primitive rocks derived from the Grampians. The large blocks seen on the beach eastward and westward of Leith, have not been rolled from a distance by the present sea; but are the wrecks of this bed of clay, large portions of which have been undermined and washed away by the tide, leaving these heavy masses behind. In proof of this, it will be observed that whenever a low sandy shore occurs of considerable breadth, as at Portobello, no boulders are seen on the beach; but where the stiff clay occurs close to the sea, the boulders present themselves.

On the Dalkeith railway fine sections of the alluvium were displayed at Whitehill Mains, three miles S.E. from Edinburgh, at the viaduct on the North Esk, and at Dalhousie Mains. I had the advantage of examining these sections in the company of Mr Jardine, the skilful engineer who conducted the work, and to whom I am indebted for most of the facts. The cut at Whitehill Mains was thirty-five feet deep; the others about twenty. The alluvium, a little farther south, consisted of three portions.

1. The lowest, which reposes on the rock, was an extremely stiff black or bluish clay, in which were thickly interspersed rolled stones of all sizes up to four or five feet in diameter; but those exceeding eighteen inches were not abundant. The lower bed at Whitehill Mains was about twenty-four feet thick; and the stones were pretty equally disseminated through it, both as to size and number, from top to bottom. This deposit, for distinction's sake, I have termed *diluvium*. The usual name is "older alluvium."

2. Above this is a bed of clay, a little redder in the colour, much looser in the texture, having fewer embedded stones, and these more angular. The two beds are not parted here by a distinct boundary; the one seeming to pass into the other; but the pickmen employed on the work, could well distinguish them by their great difference in stiffness and tenacity. In other cases, however, the line which separates the one from the other is well marked. This has been termed the "newer alluvium."

3. Above the upper clay is a bed of sand, which is almost always in strata, sometimes curiously contorted; it is generally free of stones, but sometimes accompanied by layers of fine gravel, or streaked by layers of carbonaceous matter, and occasionally passes into clay. This sand exists to a great depth on both sides

of the Water of Leith at Canonmills. A beautiful section of it was exhibited this year on the line of the Newhaven railway. It forms an arch over the top of the ridge east of Warriston House, showing strata dipping south at 15° or 20° on the south side, and others dipping north on the north side. The strata are from a foot to a few inches in thickness; they display the diagonal lamination; and some of the laminæ composed of coarse sand, are almost vertical, a position they could not have had originally. This arched bed displays, within a space of fifty yards, a series of faults, which closely resemble, on a small scale, those found in the coal strata. It rests on the diluvial clay, and extends along the high ground to Newhaven, but thins off to a depth of one or two feet. Not a single shell, great or small, has been found in it. All the three beds, the stiff clay, the softer clay, and the sand, are seldom seen at one place: the upper is only found in patches, the remains, no doubt, of a much more extensive deposit. From the appearance, composition, and arrangement of these beds, several inferences may be deduced.

First, The entire want of stratification in the lower and middle beds, their general uniformity from top to bottom, and the absence of intercalary layers of foreign matter, lead us to conclude that they were deposited, perhaps not very rapidly, but by one uninterrupted operation.

Secondly, As the alluvium is found at considerable heights, the volume of water which deposited it must have been deep. None of the diluvium is visible in Loganhouse valley, but it is seen in Eight Mile Burn, at the height of probably seven hundred feet above the sea, and I met with a portion of what seemed to be the same deposit on Westwater of Dunsyre, about one hundred feet higher.

Thirdly, It must have been in violent motion, since it has hurried along masses of ten or fifteen tons weight from a great distance, and worn the smaller ones round and smooth by friction against one another. The rolled masses are chiefly of trap, hard limestone, or other tenacious substances brought from a distance; while the sandstones and shales derived from rocks existing at the spot, are fractured into small pieces, or ground to powder.

Fourthly, We have curious evidence of the motion of the waters being protracted for a certain space of time. Blocks of three or four feet in length, were found sticking in the clay, with the upper surface, and sometimes the two flanks, beautifully grooved and dressed, while the ends or under surface were rough, or exhibited a very slight degree of smoothing. Many examples of this were pointed out to me by Mr Jardine. It shows that, after being tumbled for some time in the water, they had settled into the clay, and while their lower part was held fast, their upper surface and flanks being still uncovered, were abraded and smoothed by the stones and gravel which the current rolled over them. It follows that the space of time in which a foot of clay or less, was deposited, was long enough to permit this dressing to be executed on the surface of a hard stone.

Fifthly, There was a certain correspondence in the direction of the scratches and groovings on the large stones, which from their size, it might be presumed, had not been shifted: the direction varied through four or five points. In the alluvium at Whitehill Mains, which I consider as the tail of Cragmillar Hill, it was about one point north of east. At Glenesk and Dalhousie Mains the bearing varied from N.E. to N.N.E., coinciding generally with the course of the basin of the Esk. I did not see any dressings on large stones pointing N.W. and S.E. As the sand and fine gravel exhibited stratification, it must have been formed in a body of water either stationary like the sea, or only in a state of moderate motion.*

Near Alloa, Mr Bald found the newer alluvium to have a thickness of ninety feet, and the older alluvium no less than one hundred and sixty-two feet. In the latter no remains of shells or plants are found; but in the newer alluvium, oyster, cockle, and mussel shells occur, with trunks and branches of trees, stag-horns, and bones of animals.†

In the plain westward of Edinburgh a deep deposit of sand and gravel exists, extending over a space of four miles by two, from the Water of Leith village to Milburn, and from Slateford to Corstorphine Hill. The average height of this plain must be about two hundred feet above the sea. At several openings between Edinburgh and Gorgie, the sand and gravel are to be seen with the usual stratified appearance, and mixed with layers of carbonaceous matter derived from decayed vegetables. In the ravine from Bell's Mills to Coltbridge, the clay and gravel exhibit a depth of nearly one hundred feet. In the gravel near Gorgie, Mr Rose has found pieces of primitive rocks. This plain must have formed at a remote period the bottom of a lake, or rather a broad current, covering the whole valley. We may suppose that the waters at first flowed over their eastern (that is, their *lower*) boundary at many points. Finding, perhaps, natural fissures, occasioned by dislocations, at the two sides of the Castle, and at the Water of Leith, the current would be determined to these localities in preference to others. At the latter it would pour over the height behind Ainslie Place, forming a cataract below St Bernard's Well. This cataract, having a fall of one hundred feet, and bearing along sand, gravel, and large stones, would eat its way backward through the strata. When the great current ceased to flow, the Water of Leith would begin to operate, and, in the lapse of some thousand years, would work down its channel to the nearly uniform declivity which it now exhibits. Another portion of the great current winding along by Whitehouse Toll, and through the hollow behind Atholl Crescent, escaped by the North Loch, and a third by the hollow of the Grassmarket and Cowgate. Taking these phenomena in connexion with others, it does not seem that they can be explained by the action of the small river which now crosses the plain obliquely. I should rather consider them as the effect of an oceanic current, in its last and lowest stage, setting across this part of Scotland; or of a succession of great waves or transitory deluges in the Atlantic, such as Sir James Hall assumed to account for the groovings on Corstorphine Hill; or of tidal action when the sea stood over this district. But the absence of marine remains, and the tail of newer as well as older alluvium found *on the east side* only of projecting hills, are arguments against this third hypothesis.

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* The substance of the preceding remarks on the diluvium and alluvium was published by me in the *Scotsman* in 1828. I have not since had leisure to pay attention to the subject proportioned to its interest. M. Elie de Beaumont thinks that the gravel scattered over the east and south of France had its origin in the currents from the Alps; and that these currents arose from *debacles*, or violent and transitory inundations, produced by the sudden escape of masses of water. The alluvium of Paris contains fragments from the hills of Burgundy.—*Daubuisson Geognosie*, Tom. ii., pp. 66—611, 2d ed. Some of these may have resulted from the sudden fusion of snow. He holds also that the soil of the east of France *has undergone movements of elevation since the older alluvium was formed.—Daubuisson*, Tom. iii., p. 556—8.

† Wernerian Transactions, Vol. iii., p. 124.

Groovings and Dressings on the Surface of Rocks.—In the valley of the Forth, wherever rocks of a kind not much fissured or liable to disintegration are exposed for the first time, the surface is found to be grooved or scratched, and the prominent parts are ground off, as if the rock had been subjected to attrition by the passage of hard stones over it. Sir James Hall first called attention to this instructive phenomenon. He had observed it on the back of Corstorphine Hill; and to obviate all doubts as to its origin, he got the turf removed from a portion of the greenstone forming the western slope. I suppose this to be the area of bare rock known by the name of "Plainstones," a little north-west of the old turret. The surface, twenty or thirty yards square, is beautifully dressed and grooved. The rock dips to the west at 10° or 12°; the markings run east and west, and have evidently been produced by the attrition of stones and gravel, forced up the inclined plane by a current of water. The groovings are of many sizes, and all very nearly parallel. I noticed one three feet in breadth, and six or eight inches deep. Many may be seen about the breadth of a man's arm, but they are deeper in proportion than the large ones when they run along natural fissures, as sometimes happens. The spaces not hollowed into grooves, are either worn smooth or display fine parallel lines or scratches, to which Sir James Hall has given the name of *Dressings*. The direction of the groovings, according to Sir James Hall, is not directly to the east, but about 10° north of east.* In wandering over the western declivity of the hill, I found the surface exposed at twenty or thirty places, and invariably observed the groovings or dressings. As further evidence of the agency of a current setting eastward, I may remark that I did not see a single large boulder on the western declivity; but the moment the crest of the ridge is passed, tumbled blocks of various sizes present themselves up to ten or fifteen tons weight, lying at different heights on the eastern slope. Many of these blocks are of the rock of the hill itself. Amongst its beds there is one of a large grained syenite, easily distinguishable from any other rock in the country. Fragments of this are seen on the shores of the Forth, at ten miles eastward, and rounded masses of it, one or two tons in weight, were found in the diluvium on the line of the railway from Edinburgh to Newhaven. I have never seen a single water-worn mass of it to the westward.

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* Transactions of the Royal Society of Edinburgh, vol. vii.

There are few opportunities of observing the groovings on the Pentland Hills. I noticed them, however, in one instance at Westwater of Dunsyre, on the top of a thick bed of hard sandstone, from which twelve or fifteen feet of alluvium had been removed. The dressings pointed exactly east and west; and the evidence was the more satisfactory, as the direction of the stream on whose bank the rock was situated, and of the valley in which the stream flowed, was S. and N. They were very distinct, the larger groovings being about one and a half inch broad, and three-tenths of an inch deep. The locality must be 800 or 900 feet above the sea. The difference betwixt the older and newer alluvium was well seen here. The upper was of a loose clay, the fragments numerous, nearly all sandstone, chiefly angular, and some of them thin fragile plates, which could not have been transported more than a very short distance; the lower of a stiff red clay, the fragments few, small, well rounded, and chiefly of travelled stones, such as greenstone; and the two were separated by a sharp well-defined boundary.

At the west side of Cragmillar Hill, a quarry of hard sandstone was opened about 1825 to procure stones for the Water-works. On the newly exposed surface, Mr Jardine pointed out to me the dressings very distinctly marked, in lines running nearly east and west. I have seen marks of attrition on the top of Cockleroy, the highest of Torphichen Hills. The rock consists of trap, in pretty large columns, closely fitted; their heads are every where rounded off and smoothed; and slight groovings, four or five inches broad, may sometimes be traced for a length of three feet in an east and west direction, by an eye familiar with these markings, though the rock, from its numerous seams, is very ill fitted to preserve and exhibit them. In another respect this hill affords a fine example of diluvial action. Though the bed of trap dips to the west, and might have been expected to present an escarpment on its east side, the case is just the reverse. The sedimentary rocks have been cut away entirely from its west side, while a remnant of them exists at its S.E. shoulder, forming an isthmus like that which connects the Castle rock of Edinburgh with the ridge under the old town, and placed exactly in an analagous situation. It is worthy of observation that this is also the form of Corstorphine Hill, and of the hill on which Stirling and its castle stand. What I wish to note is the fact, that the northern end of the rock, whether trap or sandstone, is much more abraded and worn down than the south, and that the portion which has suffered least is, in each case, at the south-east angle. This is one of the circumstances which seem to me to indicate the distinct and independent action of two great currents; the first from the north or north-west, which cut down the north side of prominent rocks; the second from the west, to whose protracted but less violent operation, we owe the phenomena of Crag-and-Tail, as seen at Edinburgh and in many other localities, where a steep escarpment is presented to the west, with a tail of soft strata, soil, and boulders to the east, and deep sharply-cut longitudinal valleys on the north and south flanks of the resisting mass. Mr Delabeche has collected facts to show, that in England, Germany, Poland, Russia, and North America, there has been a movement of waters from the north to the south, transporting with them fragments of rock.* Having this evidence of a northern current from a distinct source, the facts I have noticed, though of little weight considered by themselves, seem to me entitled to attention. I have seen marks of abrasion also on the traps of Glourourem or Earncath Hill,† (between Linlithgow and Borrowstoness,) at Craigleith Quarry, and at various other localities. The direction of the dressings or groovings always corresponds to some extent with that of the valley of the Forth.

Sir James Hall observes, in his paper on Corstorphine Hill, that though the indications of a current pointed in a westerly direction at Edinburgh, he found them nearly N.W. at Torwood near Stirling, and also at Fass Castle in Berwickshire. Judging from the configuration of its channel, the Firth of Forth seems to exhibit traces of three excavating operations, proceeding in different directions—one in a S.E. direction, as shown by the line of the shore from Stirling to Borrowstoness, and by that from North Berwick to St Abb's Head—one in an east direction, corresponding with the line of the shores from Borrowstoness to Leith and Pettycur, indicated also by scratches on the rocks, and by the phenomena of crag-and-tail at Edinburgh and North Berwick Law—a third in a N.E. direction, as marked by the line of shore from Pettycur to Largo, and from Musselburgh to Dirleton Common and Fidra Isle. This last corresponds with the course of the Firth of Tay, and the central valley of Scotland, bounded by the Grampians on the one side, and the greywackĕ chain of the south on the other; and, I rather believe, must be referred to the general bearing of the strata, and of the lines of disturbance, than to the erosion of tides or primeval currents. Of the two supposed currents, that from the west must have been posterior to the other, since we find the marks of its action on the alluvium and on projecting rocks, which we may presume had been previously operated upon by that from the N.W.

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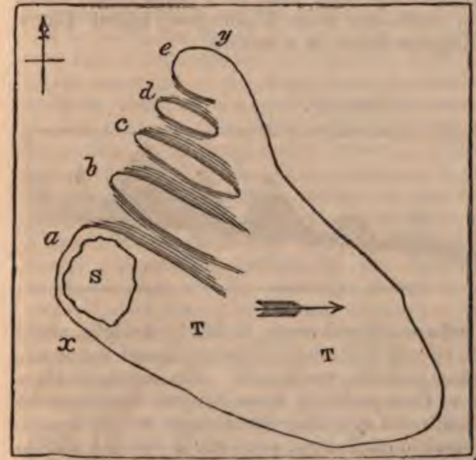
* On erratic blocks and gravel.—Manual of Geology, Second Edition, p. 181.

† These marks appear faint and doubtful in many cases to unpractised observers. To an eye accustomed to note them, the difference betwixt the natural and the abraded surface is as well marked on firm traps like Cockleroy, as between a new laid street pavement, and one that has been worn by cart wheels for many years.

In examining the trap rock on which Stirling and its castle stands, it seemed to me to exhibit very distinct marks of the action of a powerful current from the N.W.—marks of a kind unnoticed by Sir James Hall. The annexed diagram is a ground-plan of the isolated hill on which the town stands, and which rises on the west side from 150 to 300 feet above the surrounding plain. The Figure is drawn from memory, and is far from correct.

FIG. 86.



T, T, The site of the town, and S that of the castle, on the southmost ridge.

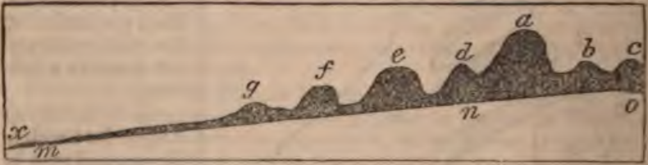
x, *y*, Hollows on the two flanks of the rock, sharply cut down to a low level.

a, *b*, *c*, *d*, *e*, Ridges into which the mass of trap is cut.

a is divided from *b* by a groove or channel about 80 feet deep; *b* from *c* by a channel 20 feet deep; *c* from *d*, and *d* from *e*, by channels of 50 or 60 feet. The portions of rock thus separated are long and narrow; the smaller have the fish shape, or that which a mass of clay or soft stone assumes when exposed to erosion by a brisk current of water; and their axes all point to the N.W. We have every reason to believe that the surface of the bed of greenstone was not originally grooved in this way; and when we seek for the cause of the form it has assumed, the current from the N.W., of which we have indications otherwise, presents us with an appropriate agent. The direction, too, agrees with that of the dressings noticed by Sir James Hall in the neighbourhood. The same current, no doubt, tore up and dispersed a great portion of the sedimentary strata which once invested it all round, covering its flanks and summit. Of these strata the only remnant now visible is found under the greenstone, forming the lower part of the steep acclivity which fronts the N.W., the trap having served, as usual, to protect the softer rocks. The trap is columnar, and its numerous vertical fissures must have facilitated the erosive action of the current. The plain is wide to the westward, and contracts here to a sort of gorge, in the middle of which the hill rises up like an island, and must have acted as a breakwater to a current from the N.W. The trap is in beds which dip to east probably at 10°, as indicated by the arrow. The part furrowed by long channels at *b, c, d, e,* consists of the lower beds. The upper had been previously removed by the same agent; for under T, T, the greenstone is much thicker, and the castle S, as well as the upper part of the town, seem to me to stand on the truncated ends of the beds.

We have an example of the same kind in a conspicuous small hill about four miles south-east from Linlithgow, called Binny Crag, of which the diagram below is a section.

FIG. 87.



The crag, which runs south and north, is nearly straight, about half a mile in length, twenty feet broad at the north end *x*, and one hundred and forty at *a*, near the south end. The general surface of the country *m, n, o,* rises probably three hundred feet from the north end *m* to the south end *o*. The whole ridge, which is composed of basalt, or basaltic clinkstone, presents a vertical cliff to the west, varying in height from six or eight feet at *x*, to two hundred at *a*, above the bottom of the narrow valley at its foot.

The southern part of the ridge has been separated into seven distinct hillocks, by channels cut across it from west to east.

The channel between *a* and *d* is about ten feet deep, measured from the top of *d*. It is only a small indentation.

d and *e* are separated by a ravine about sixty feet deep, and eighty wide.

e and *f* are separated by a ravine about fifty feet deep and sixty wide.

The hollow between *f* and *g* is about twenty-five feet deep and thirty wide, that between *a* and *b* descends probably forty feet below *b*, and one hundred below *a*. That between *b* and *c* is rather smaller.

The hillocks are joined at their bases, the whole from *c* to *x* being one continuous mass of trap. The sides of the transverse hollows are generally steep, and free of protuberant parts, and the bottom is not much encumbered by debris. The ridge is thin and sharp, its eastern side generally declining at an angle of 30° or 35°, and each of the channels passes across it at one level, or nearly so.

That these transverse channels have been hollowed out for the greater part by currents, is proved by the fact, that though the slate clay is found equally on the back of the high crags and the low, yet none is seen in the bottom of the channels. On the contrary, in one or two cases we find the truncated ends of the strata of slate clay exposed on the sides of the hollow, resting on the back of the entire part of the trap, and showing that the water had cut a passage through both rocks. It is very probable, however, that natural depressions existed originally in the trap at these hollows, and favoured the action of the water. A second and very significant fact strengthens our conclusion. The surface of the country to the westward of the ridge forms a smooth and pretty uniform acclivity, rising to the south. It is represented in the section by the line *m, n, o*. The north end of the ridge *g, x*, is on a level with the surface, or perhaps rather below it, while the south part *g,c*, projects boldly above it. The north end, in fact, would escape the erosive action of a western current, in consequence of its low and protected situation. Hence, though the slate clay has been stripped off, the portion of the trap denuded is very narrow, quite sharp, and scarcely broken by the slightest indentation. The south division, on the contrary, rising in bold relief above the general level, would be strongly exposed to the action of a current from the west. Here, accordingly, we find that deep channels have been worn across the rock, and much matter removed. And, speaking generally, we may say that *the amount of erosion and denudation is in proportion to the prominence of the rock.* The direction of the transverse channels is very nearly east and west. Proofs of denudation meet us every where in this district; but the value of the two just given, consists in showing us the direction of the denuding current.

I may add, that the summits of all the hillocks are swept clean, and are generally a little rounded and somewhat smoothed, while the top of the northern part is sharp and angular. The slate clay is always found on the sheltered eastern declivity, and never ascends to the top. A few boulders or travelled stones of small size are to be seen on the east side also, but none on the summits, and none in the transverse channels, where the current would, of course, have a free sweep.

Craglockhart Hill (three miles S.W. from Edinburgh) affords a fine example of Crag-and-Tail. It is a sharp ridge like that on which the old town of Edinburgh stands, perfectly straight, about 4000 feet in length, by 300 or 400 in breadth, and points exactly east and west. It declines gradually in height from the west end to the east, so that the back of the ridge forms nearly a straight line. The tail or eastern portion, which consists of sandstone, has been cut into a saddle shape, and is beautifully rounded, and covered with soil. The western or higher end, consists of several beds of red and blue trap and traptuff, which present themselves in angular protuberances, stripped almost bare down to the very bottom. We have, in short, a rough high protecting head of trap, and a smooth rounded tail of sandstone, probably mixed with shale. Craghouse Hill, which is only separated from it by a narrow defile, presents similar phenomena, but in a less striking form. The beds of Craglockhart Hill dip W.N.W. at 15° or 20°.

The cases now detailed of deposits of gravel and clay, of groovings on the rocks, and of denudation producing Crag-and-Tail, are given merely as *examples* of phenomena found in abundance all over the basin of the Forth.

ERRATIC BLOCKS.—These are masses of rock transported to a distance from their original seat. Most of the rolled stones in the older alluviums belong, strictly speaking, to this category ; but it is only intended to notice the more remarkable specimens. These travelled boulders are important in two respects ; first, as indicating the action of currents or other transporting agents no longer operating ; and next, as illustrating changes which have taken place subsequently to their deposition in the spots where we find them.

In the Pentland Hills I observed the following :—

A boulder of mica slate, weighing eight or ten tons, on the east end of Hare Hill. It reposes on the surface of the west side of the glen x, Fig. 54, leading north from Habbie's How to Bevelaw, on a declivity, about eighty feet above the bottom. The nearest spot from which this mass could be derived, is the portion of the Grampians about Loch Venacher or Loch Earn, fifty miles distant ; but it may have come from Cantire, eighty miles westward, from Forfarshire seventy miles northward, or even from localities still more remote. Such travelled stones are found all over northern Europe, and the means by which they are transported have been the subject of much discussion. In some cases they might be hurled along by oceanic currents ; but in others, where great irregularities of surface intervene, it is difficult to conceive that they could be carried by a stream of water. To explain the latter, the agency of icebergs has been resorted to. We may suppose, for instance, that when the low country from the Grampians to the Lammermuir Hills was still covered by the sea, the blocks in question had been locked in a mass of ice, and floated from some of the places named, by currents. Icebergs bearing large stones with them, are now drifted in this way southward from Baffin's Bay, nearly as far as the Torrid Zone.[*] Further, this block tells us that the surface of the hills where it now rests must have been in a different condition when it was deposited. It lies on the side of a declivity, where a large stone, either hurled hither by a current or dropped from an iceberg, would not stop, but roll down to the bottom of the valley. The reasonable inference is, that the valley between Hare Hill and North Black Hill, was then filled with materials, which have since been washed away.

Half a mile south from this, three greenstone boulders, of two or three tons weight each, are lying on the edge of a precipice, about 200 feet above South Burn. These have certainly travelled some miles, and the bed of clay seen below them is no doubt a remnant of that which then filled up the ravine, and prevented them from descending to the bottom.

On the east end of North Black Hill there is a sandstone boulder of eight tons weight. This block may not have travelled far; but it rests on a surface as steep as the roof of a house, (inclined both above and below at 45°,) and about 400 feet above the bottom of the valley. It is impossible that it could be dropped here, or brought to the spot by a current, without descending to the bottom, unless sustained in its place by matter since removed. This single block informs us, that the ravine, about 100 yards wide at the surface of the marsh which separates Black Hill from Belld Hill, must then have been filled up with alluvial matter to the height of 400 feet at least above its present bottom, which is probably 50 feet above the true bottom in the rock.

On the south declivity of Harbour Hill, about 300 feet above the level of the Compensation Pond, there is a very large boulder of greenstone, weighing twelve or fourteen tons. The surface it rests on is not steep; but the boulder must have travelled many miles, for there is no greenstone of the kind in the hills, and none near them, except in situations 500 or 600 feet lower. This block has probably been transported in the same manner as the mass of mica slate.

The same remarks apply to a greenstone boulder lying half-a-mile N.W. of Loganhouse, on the south side of Black Hill, about 1400 feet above the sea. It is of twelve or fourteen tons weight, and has been bored and blasted into three pieces. There are many others, in elevated situations, of three or four tons weight. The substance is generally greenstone, the least brittle probably of all rocks, and of course the best fitted to resist fracture. Nearly all the blocks have their angles rounded off.

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[*] See Delabeche's Manual, Section III., and Mr Lyell's Discourse to the Geol. Soc., p. 336—340.—London and Edin. Phil. Mag. for April 1836. The latter contains much interesting matter on this subject.

On the banks of Eight Mile Burn, in the low ground, a mass of alluvium may be seen about 100 feet thick, containing hundreds of trap boulders of all sizes up to ten tons weight. It consists of two beds—the older of a blue unctuous clay, the newer a red clay; and the large blocks are chiefly in the latter. There are many similar travelled blocks in the burn flowing down from the Old Reservoir to Bonalley, and probably in all the streams of these hills.

Besides permanent currents in the ocean, there must have been temporary currents of vast force produced by elevations of the land. Thus, let us suppose that while the Pentland and Ochil hills were both rising, but still chiefly under the water, the latter were on one occasion upheaved twelve feet along their whole length, not instantaneously, but in the course of some hours. If we call the breadth of the Ochils four miles, this elevation would dislodge fifty millions of cubic yards of water for every mile in the length of the hills, and this water would flow off in a series of powerful surges; one-half, or twenty-five millions of cubic yards, would rush away to the south with the speed of an arrow. If the summits of the Pentlands were then far below the surface of the sea, the surges from the north would affect them but little; but if they were then at the surface, or partially above it, breaches might be made in the less tenacious rocks, and much matter removed.* The effect of a series of such upheavings, (and there must have been many before the Ochils ascended to their present altitude,) would of course be much greater. The raising of the Pentlands would operate reciprocally upon the Ochils. I select the Ochils because they are of the same geological age with the Pentlands. But though the Lammermuir Hills and the Grampians, were raised above the sea at an earlier date, we may very reasonably believe that they did not attain their full elevation till the same process was begun, and had gone some length, in the Ochils and Pentlands; and currents produced by the upheaving of the older hills might therefore operate upon the newer. As a proof of such currents having existed, I would refer to the thousands of fragments of primary rocks found at the north side of the Ochils, (on the Glendevon road for instance,) in the deep beds of gravel there, which are entirely wanting on their south side. The Ochils had evidently served as a rampart to arrest the current which bore these debris of the Grampians along. The groovings in Stirling rock seem also to indicate a current from the Grampians as their cause.

Perhaps such accidental currents, from the north particularly, may have aided in excavating some of the indentations and transverse openings in the Pentlands. And one fact deserves notice in reference to this point, namely, that vast deposits of the gravel of the hills are found on their south side, but none of any importance on the north. It is true that all the larger streams flow to the south, and account for the effect so far; but those streams did not denude the flanks of Mendick Hill, nor cut the passes at Bevelaw and Craigintarrie. We have, however, no means of separating the effects of transient oceanic *debacles* from those of tides or permanent currents.

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* Those who have read Sir Thomas Dick Lauder's delightful book on the floods in Morayshire, may form some idea of the vast effects which such a mass of moving water would produce. Mr Lyell has gleaned, with his usual industry, some striking examples of the effect of great bodies of water suddenly set loose.

Erosion of River Beds.—The theory of fluviatile action in excavating the cavities in which streams flow, has been beautifully developed in Note 16 to Playfair's Illustrations of the Huttonian Theory. Rain water and melted snow must originally have found their way from high ground to the sea, by following the natural depressions of the surface. Where rocky barriers presented themselves, lakes would be formed, in which the waters would accumulate till they found a passage over the lowest part of the boundary. Where a second and third cavity occurred, the waters would collect into a second and third lake, from each of which they would escape in the same way. River channels would thus consist originally of a chain of lakes and cataracts. The stream having once found a natural fissure or hollow, would pour through it in a cataract, which, aided by sand, gravel, and boulders, would gradually scoop out the rock above, and undermine it below, and thus eat its way backward through the barrier, till the channel presented a pretty regular and uniform descent. To take a near example, we may say that the deep ravine under Moray Place is the work of a cataract which began about Stockbridge, and cut its way westward to Bell's Mills, the whole channel being now reduced to a succession of rapids, or petty falls of one or two inches in a yard. The ravine at Colinton was undoubtedly produced by another cataract, which began about Slateford. And before the barriers at these places were pierced, the waters above must have formed two lakes or wide expanses of a current proceeding from the west. The lower lake probably covered several square miles. The river St Lawrence in North America, with its chain of lakes, offers a good example of this species of action still in progress.

The cavities in which some rivers flow, apparently have either existed originally in the structure of the rocky masses, or have been excavated by oceanic currents; but there are others whose channels we may safely assert have been cut out by the streams themselves. Of this description is Dean Burn, which flows from the Old Reservoir down to Bonalley. The bed of this stream is not like what we find at some parts of the course of the Clyde and Tweed, a small gutter or groove in the middle of a wide valley. It is precisely such a channel as a mountain torrent of the size would cut for itself. Its margin is sharply defined; the sides have that uniform slope which the erosion of the stream for an indefinite period, unassisted by any other agent, would give it; and the breadth and depth are proportioned to the size and rapidity of the current. In the upper part, where the declivity is small, the bed is shallow; as the descent increases the bed deepens; and the deepest part is exactly that where the torrent has most force. When it reaches the plain, and the current relaxes, the high and steep banks no longer appear. On the other hand, the ravine of Lady Burn, the north branch of Bonalley Burn, cannot be ascribed to the small stream which runs in its bottom. It consists of the angular opening formed by the projecting edges of two inclined beds of porphyry, the upper one of which leaves a portion of the lower uncovered, (between *f* and *g*, Section VI.) This cavity was probably filled at first by sedimentary rocks, (see Fig. 51, page 132,) which great currents had washed away, before the hills arose from the bosom of the ocean. A small portion of these rocks yet remains. Most of the Highland rivers with a north-east or south-west course, such as the Spey and Findhorn, run in similar valleys, formed by the unequal extension of the strata of gneiss. It is plain, too, that Loganhouse Valley is not the work of the burn, nor the ravines at the two ends of North Black Hill, nor of the scarcely perceptible rills which flow in them. All these must be ascribed either to original inequalities or openings in the rocks, or to the action of oceanic currents.* The same remark applies to the valley between Blackford Hill and Braid Hill, to Glen Farg and Glen Devon in the Ochils, to the valleys in the Lammermuir chain, occupied by Lyne Water, Gala Water, and other streams. In Balerno Burn, on the other hand, we have a fine specimen of fluviatile erosion. It may be safely asserted that, from Balerno village to the eastern angle and a little above it, the whole ravine, a mile and a half in length, and from sixty to one hundred feet deep, has been excavated by the small stream, aided of course by frosts, snows, and rains. Kenleith Burn, from the village down to Currie, is of the same description. The larger hollows in the basin of Lyne water in Pentland Hills, are certainly the work of oceanic currents; but each of its branches down to the feeblest has cut out a smaller channel for itself. The narrow crooked ravine at Lyndale, which is probably one hundred and fifty feet deep, is clearly the work of the burn, and must have begun by a cataract about Linton village. The channel of the North Esk, where I have examined it, that is, from Pennycuick grounds to Carlops, seems to me to be due to the action of the river. From Carlops down to the junction of Eight Mile Burn, the ground on the opposite sides is perfectly level and uniform.

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* Mr Lyell, who has traced the operation of existing causes with admirable skill, recognises the agency of oceanic currents in the formation of the valleys in which many rivers flow.—See Principles of Geol. Vol. II. Fifth Edition.—See also Dr Buckland on the Excavation of Valleys in Dorset and Devonshire. Geol. Trans. Second Series, vol. i. p. 95.

The channel of the stream is a rut or groove, cut in beds of soft sandstone, generally horizontal. The depth of this channel is from one hundred to two hundred feet; the breadth from seven hundred to fifteen hundred; and there is no indication of the action of a larger current than that which now flows in it. The interesting fact here, is the vast lapse of time required to enable a small stream like the Esk to excavate such a ravine. An aged individual who had spent his life on its banks, would probably not be able, with the most careful observation, to detect, in the course of fifty years, the removal of five cubic yards of matter in a space of one hundred yards in length of the bed of the stream: yet in that space, the entire mass of matter removed since the river began to flow, must be about nine hundred thousand cubic yards. The lower course of the Esk I have not examined with sufficient care to form any opinion as to the causes which cut out its bed.

In conclusion, it may be remarked that the depth, breadth, and form of the channels of rivers depend chiefly on three circumstances.

1. The volume of water and the rapidity of its descent.
2. The hardness or softness of the rocks.
3. The position of these rocks in reference to the streams.

Channels cut right across inclined strata, are generally narrow and steep in the sides. Channels cut lengthways on inclined strata, operate with greater effect on their edges than their sides. A stream, for instance, flowing northward along beds dipping to the east, will eat its way gradually more and more to the right, or dip of the rocks. If it finds a hard stratum with softer strata above it, the more rapid erosion of the latter will carry the stream far to the eastward, and the result will be a very broad channel with a bottom inclined to the east, across the stream. Many examples occur in the Pentland Hills, where, in burns having an east or a west course, the south bank is generally much steeper than the north.

Cause of Phenomena of Crag-and-Tail.—If there has been a good deal of denudation on the east side of Scotland, there has been much more on the west. The absence of sand-banks on the west coast; the greater depth of the ocean there; the numerous and profound indentations of the land in the shape of bays, estuaries, and lakes; the rocky islands which had once been parts of the mainland; the removal of so large a part of the red sandstone of Ross and Sutherland, which had once covered a hundred miles of the western coast to the depth of two or three thousand feet, and is now reduced to a few isolated cones—all these facts, with the familiar examples of crag and tail, indicate that the surface of Scotland has been swept by powerful denuding currents coming from the west. The west coast of England and Ireland also exhibits deep indentations in high rocky land. We find the same appearances in a less marked degree on the coast of Normandy and

Brittany in France, and on a still smaller scale upon the west coasts of Spain and Portugal. The west coast of Norway is one long line of islands, promontories, and deep fiords, showing that the primary rocks, in spite of their hardness, have been breached in a thousand places by powerful currents. The western coasts of Denmark, Holland, and Belgium, having the British Isles before them as a breakwater, have few indentations except where laid open by the rivers. An effect so general should have a general cause; and, perhaps, physical geography may afford a clue to it. If the land rose in detached portions, and by successive lifts from the sea, we may suppose that there was a time when the surface of the globe consisted of a great expanse of ocean, studded with islands. Such Adolphe Brongniart supposes its condition to have been, at least in Europe, when the coal measures were deposited. In this state of things there would be three great and constant currents—one within the tropics running westward; and two running eastward between the tropics and the poles. The trade wind in the torrid zone, and the prevalent westerly winds in the extra-tropical regions, would alone account for these currents. But to these causes must be added the southward course of an under current from the pole, of *cold water*, with a low velocity of revolution, and the northward course of an upper current from the equator, of *warm water*, with a high velocity of revolution. The first would become a westerly current when it reached the tropic, and the second an easterly current when it reached the temperate zone. Such would be the state of an open ocean from the equator to the north pole, and, *mutatis mutandis*, the same description applies to the southern hemisphere. All the three currents, in truth, exist at this day, but enfeebled and metamorphosed by the transverse position of the two great continents. Now, if these currents were acting permanently, and with the force which they would have if little obstructed, their operation when tracts of land rose above the sea would be this. They would form deep indentations on the *east side* of intertropical, and on the *west side* of extratropical lands; and when acting in very favourable circumstances, would form islands, by making breaches through continents, or separating their prominent parts. The boundary between the opposite currents would be between the latitudes of 28° and 30°, where a zone of still water would exist, and their *maximum* effect would be near the equator, and within the polar circle. When the land was rising, and near the surface of the water, or partially above it, the currents would produce the phenomena of Crag-and-Tail. The crag or head would point to the east within the tropics, and to the west in the temperate and polar regions. The current would, of course, not flow invariably in one precise direction, but be occasionally deflected by high lands to the north or south of its true direction. We must keep in mind, also, that though not, perhaps, very strong, it would be constant; and that transitory storms and hurricanes would generally incorporate themselves with it, and augment its force. A temporary current evidently would not explain the facts. If the same agent swept away the solid rocks which once environed and covered Arthur's Seat and North Berwick Law, and also deposited the tail of clay and gravel lying behind these mountains, it must have acted for thousands of years. But it is more probable that there were two or more currents at distant epochs. Perhaps New Holland, New Guinea, Borneo, the Philippines, and Spice Islands, may be the remnants of what was once the southern prolongation of the Asiatic continent, and which had been breached and divided by the tropical current, before Africa and South America rose from the deep to arrest its free course. This idea, however, is thrown out merely as a conjecture on a subject requiring much additional investigation.

RISE IN THE BED OF THE FORTH.

There is satisfactory evidence to prove that the bed of the Firth of Forth, and the land on both sides of it, have been raised twenty feet or more, at an epoch which, though very recent geologically speaking, is probably long anterior to the records of history.

My attention was first drawn to this subject in October 1834, by my friend Mr Jardine, civil engineer, who met with a bed of oyster-shells in opening the soil between Leith and the Figgate Whins, for the Branch Railway. Having called my attention to the geological importance of the fact, I visited the spot in company with him, and published a few observations on the subject at the time.*

The oyster-shells extended over a considerable space along the line of the Railway, but they were in greatest abundance near the mouth of the Foul Burn, about half a mile east of Seafield Baths. The soil consists of sea sand and fine gravel, to the depth of five or six feet, in pretty regular layers, covered by vegetable earth, and resting on the stiff old blue clay seen here, at many points on the shore. The shells were amongst the fine gravel, about one foot, or a little more, under the vegetable soil. They lay pretty close together, and were so numerous, that probably a thousand might be found within a space three or four yards square. Mr Jardine observed the two *valves* of the shell in some few cases together, in their natural position; but in general they were separate, and they were sometimes broken, though more commonly each half was entire, or only reduced in size by the laminæ of which it is composed scaling off. They were of all sizes, up to five inches in breadth. Along with them, I found a few specimens of the Buccinum (Bucky) three inches long; a few of the Cardium Edule (Cockle,) and of the Pecten; rather more of the Patella (Limpet;) and considerable numbers of the Turbo of various sizes. All these shells are identical with species found in the waters of the Forth, and live generally at a depth varying from six to ten fathoms.[*] I saw no specimens of the Mussel, which is a littoral shell, living between high and low water.

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* *Scotsman* Newspaper of Nov. 1, 1834. I was not then aware that the shells had been exposed many years before, and described by Professor Jameson to his class. I have transferred the remarks I then published on the oyster bed, and the ancient sea-cliff at Newhaven, into the present section.

The stratum of gravel in which the shells were chiefly found, was from six to eight feet above the highest spring tides, and about twenty-six or twenty-eight feet above the lowest level of low water. Now, oyster-beds are found at all depths to 100 feet, but never, I believe, in spots left dry by the ebb tide. The oyster-shells in the gravel were therefore about thirty feet above the level where the fish now lives, and the same remark applies to most of the shells found along with them ; while the mussel, which is absent from the deposit, has its abode between high and low water.

In passing eastward along the line of the beach, where the stiff blue clay is exposed by the action of the tide, the oyster-shells were seen thinly distributed above the clay, and covered by two, three, or four feet of sand, but still about the same height above the sea. They were also seen in a ditch on the south side of the road, 50 or 100 feet back from the present beach, and in all probability two or three hundred feet from the line of the beach some centuries ago; for a portion of the soil here is annually cut away by the waves.

In an opening of the soil opposite the Chain Pier, more than two miles to the westward, I found at the same time a layer of shells about a hundred feet from the beach, and nearly at the same level with those at Foul Burn. They belong almost entirely to the genus Turbo, with sand or fine gravel above and below, and lay so close as to form almost a continuous stratum: a few of the genera Cardium and Patella were intermixed.[†]

Whoever has passed along the shore westward by Newhaven and Trinity, must have observed a small bank or acclivity, running nearly parallel to the beach, at the distance of sometimes 100 feet, sometimes a quarter of a mile inland. It seldom presents a gentle inclination, but in general rises sharply and suddenly, with a rounded outline, to a height varying from fifteen feet to sixty or eighty. It is divided from the sea by a narrow stripe of ground with a remarkable level surface, rising from four to fifteen feet above high water. Except at a few places where the rock crops out, this low plain consists of sea sand and fine gravel, or of stiff blue clay, with a covering of sand, one, two, or more feet thick. It is in this covering of sand that the deposits of marine shells are found.

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[*] See table at the end of Delabeche's "Researches in Theoretical Geology," for he depths at which various shellfish are found.

[†] Under the name of "Shell Gravel," Brongniart has described similar deposits in various parts of Europe. Among these are a bed of shells fifty feet above high water, on the coast of La Vendee; one fifty-six feet above the Mediterranean, near Nice, &c.—*Tableau des Terrains*, p. 84. Mr Lyell has gone largely into the subject in his Address to the Geological Society in February 1836, and in his Principles of Geology. Vol. iii. chap. 10.

This acclivity I have traced along the whole coast from North Berwick to the mouth of the Avon, and from Crail to Crombie Point, (the western limit of my journeys,) except at a few spots, such as Portobello and Dirleton, where the land rises so gradually from the shore that the sea, when higher, would merely push its surges farther inland without breaching the surface. Even if no shells had been found at a higher level than the water now attains, this well-marked acclivity might have been received as decisive evidence of the land being raised, or the sea having receded. It presents itself in various forms, of which the diagrams below will convey an idea.

Fig. 88.

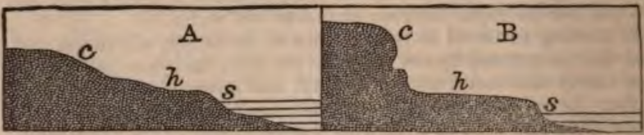


Fig. A. Where the land has been laboured, or is very loose, the acclivity has this form, as near Carolina Park, and eastward of Seafield. Here *c*, the ancient sea-cliff, slopes gradually down to *h*, the ancient beach or sea bottom, on which the deposits of shells are found, and *s* is the present shore, rising five or six feet above high water.

Fig. B. Here the ancient sea-cliff, *c*, rises abruptly from *h*, the ancient bottom, which is often a dead level. In this case, *c* is either of the old stiff diluvium, or of rock. We have an example of the former at Trinity, where the acclivity, though not so sharp as in the Figure, is too steep for cultivation, and where the diluvium is now well exposed in the opening made for the Railway. The breach made by the sea close to the Battery, where the diluvium presents a mural front, shows what the old acclivity originally was. From a point near Hopetoun, to the mouth of the Avon, we have specimens of the sharp cut sea-cliff in all its varieties, and of all heights from 30 to 120 feet. Bridgeness and Borrowstoness stand on the ancient beach, very little above the level of high water, and the bare escarpment of rock, 100 feet high behind them, is the ancient sea-cliff; and though it has been partially quarried, it is probable that the caves and recesses seen at some parts are the work of the sea.

Fig. 89.

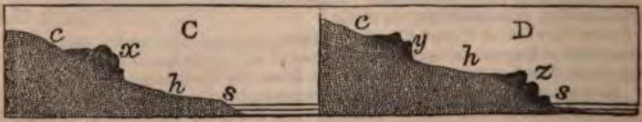
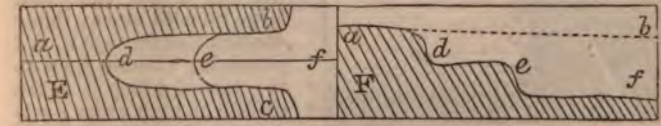


Fig. C. In some cases we have the ancient tidal action finely exhibited by an isolated crag *x*, projecting from the sloping surface of a field. There is an example at the east end of the village of Limekilns. The ground falls toward the sea with a very gentle inclination; the subsoil consists of soft shale, which was cut away by the water with ease; but in the middle of it was a bed or mass of hard sandstone, upon which the fury of the waves produced much less effect, and which now stands out in relief, bearing witness to the destructive action of the tide upon the softer rocks around it. It is about 200 feet back from the present line of the shore, and the lowest part of it is probably fifteen feet above high water.

Fig. D. In other cases the old sea-cliff is precisely a copy of the modern one. At a place westward from Rosyth Castle, we have, for the space of a furlong, a pretty firm sandstone, *z*, two or three yards thick, which is washed by the high tide. It is covered by a bed of shale, above which is another bed of sandstone, *y*, like the first. The second bed of sandstone exhibits the same water-worn front as the other, runs parallel to it at the distance of from forty to one hundred feet, and is divided from it by a stripe of grassy soil, which the ancient tide, by washing away the shale, had worn down to a moderate declivity, precisely similar to the present beach. We have, in short, the ancient sea-cliff *y*, the counterpart of *z*, and the ancient beach *h*, the counterpart of the modern beach at *s*, when the tide leaves it dry.

Fig. 90.

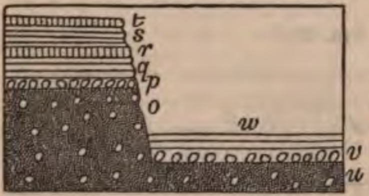


Figs. E, F. (In these two figures, E is a ground plan, and F a section of the same objects.) At a promontory which forms the west point of the bay of Elie, in Fife, there is a bed of columnar greenstone, *a*, *b*, *c*, (Fig. E,) in which the tide has hollowed out a cavity *e*, like an arm-chair with solid sides. Just above it there is a cavity *d* of the same breadth, and precisely similar in all respects, except that its bottom is some yards higher, and it is dry, because it is above the level of the tide. Fig. F, represents a section along the line *a*, *d*, *e*, *f*, in which *d e* is the ancient cavity, and *e f* the modern. If the position of the rock had been remote from the sea, we should have been puzzled to account for the curious recess *d*; but the enigma is solved at once when we find the tide playing in the similar recess *e f*, a few yards lower, and extracting column after column, by the same process which has hollowed out Fingal's cave in Staffa. We see the agent at work, and can easily comprehend that when the tide rose twenty feet higher, its excavating power would operate at *d*, precisely as it now does at *e*.

It must be kept in mind that what have been described are not rare phenomena, met with at distant intervals. Rounded declivities as shown in A, or sharp precipices as in B, or projecting rocks as in C and D, or excavated recesses as in E, present themselves in an almost unbroken line along the shores of the Firth; moreover, they occur only at places a few yards above the tide level: and when we pass inland along the rising surface of the country, to a height exceeding fifteen or twenty yards, they disappear.

The resemblance between the ancient and the modern beach may be traced still farther. The sea is continually encroaching on the coast wherever it presents a mural front. The action of the tide undermines the steep bank; the clay is broken down, and washed away: and the large travelled boulders inclosed in it, are strewed over the new bottom. A necessary consequence of this is, that the stones, thinly disseminated through six or eight feet of clay, when all collected on one level, seem much more crowded, as they are really much nearer one another. Now, on examining the vertical clay bank at the mouth of the Foul Burn, it will be seen that the ancient bottom corresponds with the modern in this particular also.

FIG. 91.



In this section, (at right angles to the coast line,) *o* is the bed of stiff clay, with large rounded stones thinly disseminated through it, and presenting a mural front to the sea, of which *w* is the surface at high water; *p* is a layer of the same sort of rounded stones resting on the upper surface of the clay, and lying much closer together than the embedded stones; *q*, beds of sea-sand and fine gravel, with oyster and other shells in it; *r*, a bed of turf or vegetable soil, half a foot thick; *s*, a bed of drift sand without shells, from a few inches to two or three feet in thickness; *t*, a second stratum of turf, forming the present surface of the low plain; *u*, the remains of the bed of clay on the beach, once as high as at *o*; *v*, the boulders washed out of that portion of the clay which has been swept off, lying thickly together, and forming the counterpart of the layer at *p*. We see that the layer of boulders on the beach at *v*, are the spoils of the present sea-cliff *o*; and it is curious that we find a similar layer *p* on the ancient beach, proving that the same work of destruction went on at a higher level. At other points of the coast, a bed of sand is found above *v*, covering the boulders, as the bed *q* covers the boulders at *p*. This curious feature of resemblance betwixt the ancient and the modern shore, was pointed out to me by Mr Jardine. The presence of two beds of turf is probably accidental, as the rivulet called Foul Burn is impregnated with manure, and produces grass where it would not grow without such irrigation.

At Kinneil, three miles westward of Borrowstoness, there is a well-known large bed of oyster shells, which I have visited several times. They lie conformably on a declivity, about half a mile from the present shore, and thirty-six or thirty-eight feet above the high water level. They are seen under a garden fence along a space of twenty or thirty feet. The visible part of the bed is about three feet thick, and the shells are regularly disposed on their sides, resting on one another, with very little sand or soil intervening. A bed of sea shells was found by Mr Hamilton, from five to fourteen feet above high water, about two miles eastward of Elie.[*] A friend of mine recently found a similar deposit at Blackness (fourteen miles west from Edinburgh,) about six feet above high-water; and at various points between Charleston and Aberdour I observed comminuted shells, mixed with a few entire ones, forming a large proportion of the soil, from the high tide mark up to the height of eight or ten feet above it.

The skeleton of a whale, pretty entire, was found a few years ago at Airthry, about two miles north-east of Stirling. It was embedded in a fine clay, about twenty feet above the level of the highest tides. About seven miles farther west, near the head of Blair-Drummond Moss, part of the skeleton of another whale was found resting on peat, covered by the fine clay called the Carse clay, and which, in its turn, was covered by peat-moss. At various parts of the Carse of Stirling and Falkirk, also, sea shells are found in the soil.[†]

These various facts clearly show, that either the land has risen, or the sea has subsided. But a subsidence of the sea, if it takes place, must be universal and every where equal; and since this is inconsistent with what is known of other countries, the only admissible conclusion is, that the bed of the Forth, and the land on both sides of it, have been elevated. The position of the oyster bed at Seafield implies a change of level of not less than 30 feet; and from observing the heights at which tidal action is visible on the ancient coast line, I am led to think that a rise of 30 or 35 feet is most consistent with the phenomena generally. The head of the oyster bed at Kinneil is nearly 40 feet above the sea; and if the difference between high and low water was as great at the ancient epoch as now, this indicates a rise of not less than 60 feet, but which may be twice as much. The other facts appear to be at variance with the supposition of so great a change; and it seems therefore probable that the remarkable elevation here was the consequence of a dislocation, and merely local. In the coal-fields there are often several faults within the space of a mile; and there is nothing unreasonable in assuming that more than one may have been produced in the 20 miles between Leith and Kinneil, even subsequent to the comparatively recent epoch at which the elevation took place. This conjecture derives some confirmation from the form of the ground. A long elevated tract, consisting of sandstone and shale, rising to the height of 150 or 200 feet above the sea, skirts the shore here, and terminates at the mouth of the Avon, where the oyster bed is found. The land immediately to the westward, sinks down 100 feet at once. The sudden change may be partly owing to a dislocation; and it is probable that the Avon runs in the fissure which divides the raised beds from the depressed. If the caves in the sandstone cliffs behind Borrowstoness are the work of the sea, it must certainly have stood at a higher level than the present by 60 or 70 feet.

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[*] Philosophical Magazine, October 1835.

[†] Paper by Mr Blackadder, Wernerian Transactions, Vol. v., p 424.

At places where the beach rose very gradually, the sea, when it receded, would leave a tract of sand. This has been the case at Dirleton, where the soil for half a mile inland is covered with it. The wind, acting on this loose substance for ages, has blown it into some hundreds of hillocks, of various heights from six feet to thirty. The lower part of Goolan Links consists also of sand; and there are many other places similarly circumstanced.

When the sea stood 35 feet higher than at present, it must have covered the site of South Leith entirely, ascending as far as Springfield Foundery and Bonington Toll, and along the water-course to a point near Stockbridge. It would form here a narrow bay or inlet, about two miles long and a quarter of a mile broad; and it was perhaps by the action of its tides that the thick bed of sand, of which portions are seen at Canonmills, in Warriston grounds, at the old Botanic Garden, and elsewhere, was divided and broken up.

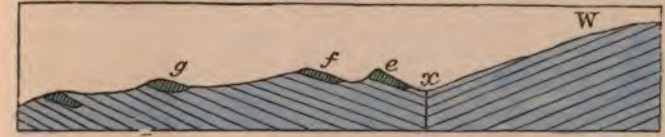
Marks of a similar change are numerous on the west coast of Scotland. On the shores of Arran I found almost every where an ancient beach, in the shape of a low platform, from two to eight feet above high water, and from one or two yards to a furlong in breadth. Behind it is either a pretty steep acclivity, or a vertical precipice. Caves have been hollowed out by the ancient tide in the precipice, to the height of 30 or 35 feet above the present high-water mark. Some of these caves recede 30 or 40 feet inward from the front of the rock above, and are occasionally used as sheds to protect carts and ploughs from the weather. Their original position was probably between high and low water; and chiefly on this ground I estimated the elevation of the land there at 35 feet.

SINCE the preceding article was written, an elaborate and able paper on the subject has been published by Mr Smith of Jordanhill, in the Edinburgh Philosophical Journal for October 1838. In this paper, besides stating the results of his own researches, he has united a vast number of scattered notices respecting changes in the relative levels of sea and land, and weighed the results with great care. He has found, among 180 species of fossil shells, 14 which appear now to be extinct, and which therefore indicate an apparent change in this department of organic life since the bed of the sea was raised. The paper is highly interesting.

Correction of Section XI. of Pentland Hills.

OWING to an inadvertency in copying a faulty sketch taken in an early journey, the north end of this section is incorrectly delineated. It should have been as in the diagram below.

FIG. 69.



The letters *e, f, g,* represent the objects so marked in the section.

W, Is the north end of the West Cairn Hill.

x, Is a slip or dislocation which was inadvertently omitted in the section. This slip is not actually visible; but an examination of the ground in the burn which flows down from Caldstane Slap, and in Colzium Burn, convinced me of its existence.

THE END.

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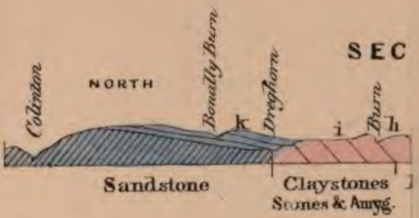
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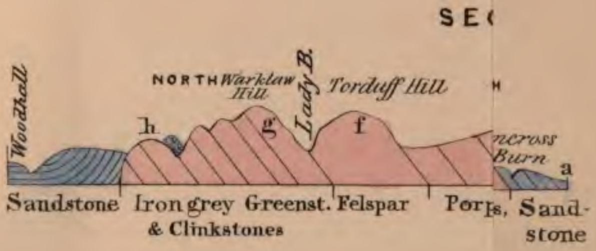
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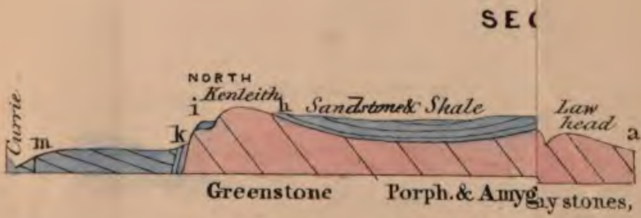
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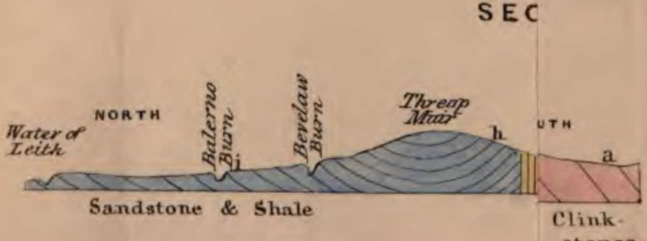
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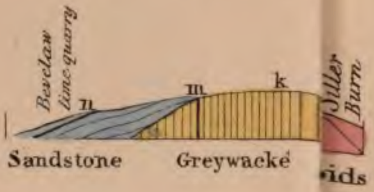

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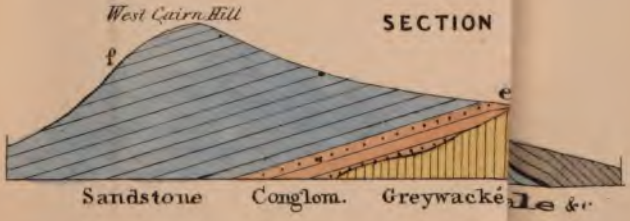

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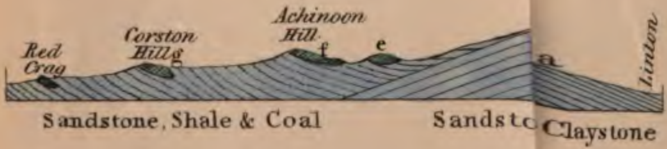

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